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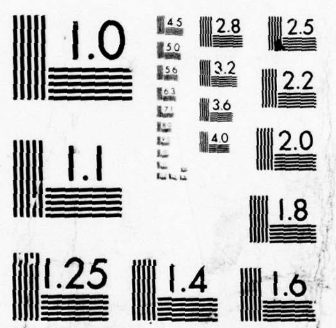

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AN EVALUATION OF ASPHALT-RUBBER MIXTURES FOR USE IN PAVEMENT SYSTEMS

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The design and construction of airfield pavements have not been developed sufficiently to provide pavements that will not crack. Cracking is a response to traffic and environmental conditions or to the construction material. For many years, rubber in several different forms has been added to asphalt with limited success in reducing pavement cracking. This report reviews the efforts to control cracking by incorporating rubber and asphalt for application as membrane interlayers, surface seal coats, crack fillers, and joint sealers. The extensive literature review indicates that conflicting conclusions have been reached

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regarding varied applications of the asphalt-rubber material. Of the asphalt-rubber products available, those with high percentages of rubber (20 to 30 percent by weight) appear to be the most promising for airfield pavements, although the effectiveness of asphalt-rubber in controlling or reducing pavement cracking has not been conclusively demonstrated. No superiority of one asphalt-rubber product was indicated in the literature. Because of the danger of loose aggregate chips, the literature indicates that chip seal applications should not be used on facilities where loose chips could be a problem. Therefore, the membrane interlayer is the only application of asphalt-rubber that should be considered for military runways at this time. Chip seals might be applicable for pavements other than runways. No documentation is available on the use of asphalt-rubber for crack and joint sealers/fillers or for pond liners, but the material has been used successfully for these applications. Laboratory tests to predict the performance of the asphalt-rubber material and field tests to determine the correct heating and mixing time and temperature for the asphalt and rubber are critically needed.

PREFACE

This report documents work performed during the period April 1977 through February 1979 by the University of New Mexico under contract F29601-76-C-0015 with DET 1 (CEEDO/CNG) HQ ADTC, Air Force Systems Command, Tyndall Air Force Base, Florida 32403. Donald N. Brown managed the program.

This report has been reviewed by the Information Officer and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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INTRODUCTION

BACKGROUND

Airfield pavement design and construction have not yet progressed to the point at which pavements that will not deteriorate can be constructed. Deterioration appears in the form of cracks, which occur in response to such factors as differential vertical movement of the pavement, direct tensile stresses within the wearing course, thermal effects, material shrinkage, repeated flexure, and reflection cracking. The rate of deterioration is a function of the design method, construction procedure, materials, gross aircraft load, aircraft traffic volume, and environmental conditions.

Although there has been no significant advance in improving the properties of asphalt within the past 30 years, some contemporary success with the use of rubber to modify the performance of asphalt in pavements has stirred a renewal of interest in rubberized asphalt or asphalt-rubber. Note that such terms as rubberized asphalt or asphaltized rubber have no real meaning unless the characteristics of one material are completely overcome by the other. There seems to be no evidence of significant (if any) chemical reactivity between asphalt and rubber, nor does it appear that these two materials may ever be in complete and total solution one with another. At best, rubber and asphalt may be blended or mixed and partially solubilized. For purposes of consistency, the term asphalt-rubber will be used in this report.

OBJECTIVES

The objectives of this study were (1) to evaluate the state of the art of using asphalt-rubber mixtures in the design, construction, and maintenance of airfield pavements; (2) to evaluate the effectiveness of asphalt-rubber for controlling or reducing cracking in airfield pavements; (3) to investigate the use of asphalt-rubber for application as membrane interlayers (known

as stress-absorbing membrane interlayers, or SAMIs), surface seal coats (known as stress-absorbing membranes, or SAMs), crack fillers, and joint sealers; and (4) to recommend a research plan for evaluating the potential uses of asphalt-rubber in airfield construction, maintenance, and repair.

APPROACH

The study was conducted by means of an extensive literature search, discussions with consultants, visits to job sites where asphalt-rubber had been used, and interviews with users and proprietors of asphalt-rubber.

REPORT ORGANIZATION

Section I of this report defines the problem and outlines an approach to the study. Sections II and III provide a review of the literature on asphalt-rubber. Section II deals solely with conference literature from the 1971 *International Symposium on the Use of Rubber in Asphalt Pavements.* This material is placed in a separate section because it provides extensive early documentation on the subject of asphalt-rubber. Section III reviews selected literature chosen to show the range of ideas on the subjects of types of rubber used in asphalt-rubber, the reaction of rubber to liquid asphalt, and the properties of asphalt-rubber. The references are from the United States and seven foreign countries. The authors are from universities and governmental laboratories or are users, producers, or consultants. Section IV describes contemporary processes and application techniques used to incorporate asphalt-rubber in paving projects. Performance evaluations of some of the test sections and projects in which asphalt-rubber was used are discussed in Section V. Unfortunately, a great many of these projects have not been documented. In addition, project evaluation has not been consistent, geographical and ambient conditions have differed, and in some cases not enough time has elapsed to allow a thorough evaluation. Thus, Section V is not complete, nor can it be made so. Section VI contains a summary of the study and concludes that asphalt-rubber is a useful product that should be further developed. A recommended research plan and budget are presented in Section VII.

SECTION II

SELECTIVE REVIEW OF PROCEEDINGS OF INTERNATIONAL SYMPOSIUM ON USE OF RUBBER IN PAVEMENTS

INTRODUCTION

In 1971 an international symposium on the use of rubber in asphalt pavements was held in Salt Lake City, Utah. Sponsors of the symposium were the Utah State Department of Highways, the University of Utah, and the International Institute of Synthetic Rubber Producers. A review of the symposium proceedings is presented in this section.

HISTORICAL BACKGROUND

New engineering materials and combinations of such materials have historically failed to gain instant acceptance among engineering designers. The use of rubber in asphalt is no exception. According to D. C. Thompson of E. I. du Pont de Nemours and Co., Inc. (Reference 1), the French generally are given credit for installing the first road with a rubberized bituminous surfacing. Charles de Caudemberg of Nice, France, was granted German Patent No. 116,126 on December 10, 1899, for rubberizing pavement. An asphalt-rubber paving company was established in France in 1901, and a road is reported to have been surfaced with a rubberized composition in Cannes in 1902. Thompson further reports that on August 20, 1873, more than 26 years before de Caudemberg received his patent, U.S. Patent No. 142,601 was issued to Samuel J. Whiting for an asphalt paving composition containing 1-percent balata. In Reference 2, F. S. Rostler, well-known rubber and asphalt technologist, cites

References

1. Hoiberg, Arnold J. (Ed.), *Bituminous Materials: Asphalts, Tars, and Pitches*, Vol. I, Interscience Publishers, New York, New York, 1964, p. 377.

2. Elmer, Lowell, and Rufener, Brent (Eds.), *Proceedings of the International Symposium on the Use of Rubber in Asphalt Pavements*, Utah State Department of Highways, Salt Lake City, 1971, p. 163.

26 patents issued by the United States Patent Office for various asphalt-rubber combinations and applications. Undoubtedly, numerous foreign patents exist.

H. A. Endres, manager of the Research Applications and Services Division of the Goodyear Tire and Rubber Co., reports that by the year 1959, at least 10 states had specifications for rubberized binders in surface treatment and seal-coat construction as disclosed in a survey made by the Highway Research Board (Reference 3).

Victor Sorbe, of the Utah State Highway Department (Reference 2, pp. 27, 28), reports an estimate by the International Institute of Synthetic Rubber Producers showing that by the early 1960s some 10,000 miles of rubberized roads existed throughout the world. Some of these roads were 40 years old at the time the estimate was made; apparently, however, no accurate performance records had been kept or were made generally available. This situation is described by C. Capitani, Assistant Managing director of ANIC, Milan (Reference 2, pp. 263-64):

> A survey of road rubber applications in Europe shows a lack of systematic development of this important problem. This can be explained only by the fact that each development took place separately and in a different way in each country and even within various organizations of the same country.
>
> Which were the main reasons for this situation? They must be attributed to the fact that, even in a single country, research and construction were at very different dates and developed separately by private companies concerned with the secrecy of their findings, while they hoped for greater economic advantages due to their priority. Not only every effort was made to keep these developments secret from competition, but there was no cooperation between natural and synthetic rubber producers on the one part and asphalt or tar producers on the other part, and not even between raw materials producers and road constructors.

It might be safe to assume that the situation in the United States has been similar.

Reference

3. Endres, H. A., *Latest Developments in Rubberized Asphalt*, Bulletin 48, No. 8, University of the Pacific, Stockton, California, 1961.

GREEN RIVER PROJECT

Nearly 130 pages of the symposium proceedings are devoted to the Green River Project, a well-planned experiment with comparative types of roadways. In 1968, the Utah State Highway Department, in conjunction with the Civil Engineering Department of the University of Utah and the International Institute of Synthetic Rubber Producers, constructed 16 experimental test sections as part of an actual federal-aid construction project on U.S. Highways 50 and 6, about 10 miles north of Green River, Utah. The experiment was a 5-factor, 2-level, half replicate of a 2^5 fractional experiment. Apparently, all phases were carefully performed, from the preliminary laboratory investigations to the actual construction, sampling, laboratory testing on field samples, selection of types of tests, and statistical analysis. However, the project had one fault: only one type of rubber was used and that in a single amount (3 percent).

The synthetic rubber used in the test sections was furnished by the Synthetic Rubber Producers through Goodyear (Reference 2, p. 113). Apparently little thought was given to the reasons for selecting Pliopave Latex L-170. During a question and answer session in the course of the symposium, Ronald Vokac, asphalt consultant, reported that the experiment had been set up primarily to show

> . . . what a rubber will do in an asphalt that is used in a mixture and put in a pavement . . . we haven't had anybody document an answer to that question [why was only one type of latex used?] so it didn't seem necessary at this time to use more than one rubber in order to obtain a measured series of effects and interactions from such an experiment (Reference 2, p. 41).

Despite its failure to examine the effect of various types and amounts of rubber, the Green River Project generated a great number of observations and conclusions on the part of the symposium participants that would be of value in further investigations. The following is one interesting conclusion:

> The test data of the entire project do not indicate an accurate picture of the properties of rubberized asphalt. This is not the result of inadequate planning and testing. Rather, it is an inherent weakness of the standard tests. It is caused by the fact that the tests are related to original asphalt and not

aging material. The standard test temperatures are more related to mixture, laying, and compacting than performance. This may indicate trends but is not specific enough to tell what is really happening (Reference 2, p. 89).

Investigators in the Green River experiment found too little change in the 16 test sections after 24 months to permit a high level of confidence in the field evaluation. Therefore, the observation period was extended to a total of 5 years. The results are presented in a final report dated June 1976 (Reference 4). Pertinent excerpts follow:

> As a consequence of the poor disbursement of rubber in the mix, resulting from adding it at the pugmill, it is likely that many of the beneficial as well as adverse effects of rubber have been distorted (p. 123).
>
> Numerous examinations in the field and the indirect evaluation of tests show that addition of rubber to either the high or low viscosity asphalt resulted in more cracking (p. 136).
>
> If the 16 test sections are order ranked in terms of PSI (Pavement Serviceability Index), those sections with a thin bituminous surface (3"), no rubber, high viscosity asphalt (Casper-source) and a rich [mix], 1.10% of design, gave the best overall performance. Unless too much asphalt caused instability or bleeding, there was no doubt that additional asphalt, all other factors being equal, would give a better performance (p. 143).

The following is one of the overall effects reported:

> [It is recognized] that 'rubber' has a place in highway maintenance and construction that can result in cost savings. The State of Utah uses at this time some form of rubber in all crack sealing operations; the rubber is used either in the form of latex, neoprene or crumb rubber. At this time it seems preferable to conventional asphalt. Chip seals have been laid and constructed using rubberized asphalt. Up to date they show excellent performance (p. 142).

With further reference to the Green River experiment, the International Institute of Synthetic Rubber Producers, after conducting 1250 individual laboratory tests on 16 rubber-asphalt combinations, indicated (Reference 2, p. 28) that rubber affects asphalt by making it (1) more viscous; (2) more

Reference

4. Peterson, Dale E., Sorbe, Victor K., and Lai, James S., *Evaluation of the Use of Synthetic Rubber in an Asphalt Pavement*, Report No. UDOT-MR-76-5, Utah Department of Transportation, Research and Development Unit, Salt Lake City, 1976.

ductile at low temperatures; (3) more adhesive; (4) more elastic, (5) more impact-resistant at low temperatures; and (6) more flexible, tenacious, and tough.

After testing 80 mixtures of the 16 rubber-asphalt combinations with aggregates, the Institute indicated that rubber in the amount used (3 percent) imparts to the asphalt concrete mixes the following qualities in terms of the Marshall Design characteristics (Reference 2, p. 29).

1. Greater compressive strength either wet or dry.
2. Slightly less flow.
3. Makes possible the use of higher asphalt contents which in turn reduces voids while maintaining stability or compressive strength.

Wade Betenson, Utah State Department of Highways, reported on the Green River project as follows:

> When rubber is added there are more cracks. . . . By varying the design combinations, a mix has been constructed that will induce failure with the addition of rubber. Where the pavement was weakened with low viscosity asphalt and then stiffened with the addition of rubber, the pavement was prone to crack (Reference 2, p. 85).

In spite of the above, Betenson offered the following (Reference 2, p. 87):

> What does proper rubberizing contribute to asphalt as a binding medium? Our test results indicate that the improvements can be generally grouped as follows:
>
> 1. Added strength or toughness.
> 2. Higher asphalt content and thicker film of asphalt.
> 3. Improved adhesion.
> 4. Greater stability at higher temperatures.
> 5. Improved flexibility at lower temperatures.

Following the presentation of the final paper on the Green River project, Mr. C. M. Hewett, American Oil Company, stated: ". . . I am very impressed with the laboratory data, but not with the test results that you've got at Green River, which is what counts. The pavement tells what happens, and I can't see how you can justify paying a nickel more for the differences you have shown so far." Mr. W. J. Liddle, Utah State Department of Highways, responded by saying, "We think we need to go to further studies

on cracking. The cracking does not support the conclusion that rubber will eliminate cracking" (Reference 2, pp. 123, 125).

COMMENTS BY F. S. ROSTLER

In his symposium paper, entitled "Rubber in Asphalt Pavements," F. S. Rostler made the following pertinent observations:

> Defining a rubber by trade name alone and describing it by its physical form won't do any more. Rubber to be used in rubberizing asphalt must be tailor-made for the purpose and must be made to comply with requirements to be defined by the engineers. The time when any material which could be called a rubber was considered a candidate for use in pavements is past. If this is not recognized, further indiscriminate field experiments with rubberized asphalt will add little useful information (Reference 2, p. 138).

Further, Rostler points out that only the following have been extensively tested:

(1) Natural rubber (poly [isoprene]) in the form of unvulcanized crumbs and latex and in the form of slightly vulcanized crumbs, (2) styrene-butadiene rubber (SBR) in the form of latex and as various powders mingled with fillers, (3) neoprene almost exclusively in the form of latex, (4) reclaimed[1] rubber in the form of crumbs or powder, and (5) ground scrap in various mesh sizes (Reference 2, pp. 138-39).

Rostler also points out that natural rubber, SBR, and neoprene come in too many variations to mention and are not commercially well-defined materials. He adds that both reclaimed rubber and scrap rubber are vulcanized and are therefore somewhat similar and more or less inert (Reference 2, p. 138).

For clarification of some of the material presented here, it is noted that vulcanized rubber is insoluble in asphalt (Reference 2, Levy, p. 296). Neoprene is another rubber that is not soluble in asphalt according to Rostler (Reference 2, p. 259). (A rubber [Solprene GEO] that is soluble in

Footnote

[1]Reclaiming is essentially depolymerization; the combined sulfur is not removed.

maltenes and is compatible with all types of asphalts is discussed in a later section of this report.)

Devulcanization is another term that frequents the literature. Vulcanization is the process of heating a mixture of crude or synthetic rubber with sulfur, sulfur compounds, or other chemicals to produce cross-linking of the rubber molecules in order to impart to the rubber useful properties such as elasticity, strength, and stability. It is almost impossible to reverse the cross-linking; therefore, the term devulcanization is a misnomer. The term really means that the rubber is softened so that it may be milled to form a coherent sheet on the mill or refiner (several means of accomplishing this purpose are described in Reference 5); therefore, the term replasticizing might be more appropriate than devulcanizing.

Rostler has summarized reported findings on the effects of rubberizing asphalt (Reference 2, pp. 139-141); his summary bears repeating here:

1. Rubber is an elastomer; i.e., a material which possesses elasticity and extensibility over a range of temperatures, and imparts these properties to asphalt if properly incorporated. The fact that most elastomers don't have strength and elasticity in the unvulcanized state is considered unimportant by most investigators.

2. Rubberized asphalt pavements contain rubber in one or more of the following forms:

   (a) as an integral part of the asphalt cement, i.e., not discernible with the naked eye or under the optical microscope as separate particles.

   (b) as a network throughout the asphalt cement, visible under moderate magnification or with the naked eye when pulling apart the asphalt-aggregate mix.

   (c) as an elastic aggregate visible with the naked eye as individual particles distributed through the asphalt concrete.

Reference

5. Rogers, S. S. (Ed.), *The Vanderbilt Rubber Handbook*, Ninth Ed., R. T. Vanderbilt Co., New York, New York, 1948.

3. When adding rubber in the form of latex or finely divided unvulcanized hydrocarbon rubber (natural rubber or SBR) with sufficient heating and mixing, at least a portion of the rubber added to the asphalt becomes part of the asphalt cement. This portion of the rubber is often called "effective rubber." [NOTE: Rostler later stated: "Even in the form of latex, the rubber is still added solid. It is first dispersed in the water" (Reference 2, p. 201).]

4. When adding rubber in the form of vulcanized or slightly vulcanized rubber or together with sulfur, or when employing insufficient heat and time in adding it to the asphalt, the rubber is primarily present in the asphalt as a network and/or partially swollen particles.

5. When vulcanized scrap or reclaim is added to the asphalt, the rubber constitutes an elastic aggregate.

6. The majority of investigators believe that rubber after addition to asphalt should be in or near solution in the asphalt to be effective as a modifier.

7. The principal disadvantages quoted in the literature and observed in practice are mechanical difficulties encountered in producing the rubber-asphalt mixtures and placing the mixtures.

It can be concluded from the findings presented in the literature that all of the above statements are correct in a qualitative way and thus substantiate the statements made by all investigators that, theoretically, asphalt pavement will benefit from addition of rubber, provided that a suitable rubber is added in a suitable manner.

To quote again from Rostler's paper (Reference 2, p. 141),

The advocates of rubberizing asphalt cite the following benefits as the ten most wanted:

1. increased softening point
2. increased toughness
3. increased elastic recovery
4. increased ductility
5. increased retention of aggregate (in surface treatment)
6. improved low temperature flexibility
7. improved durability
8. high resistance to compaction under traffic
9. decrease of bleeding tendency
10. decrease of temperature susceptibility

Rostler concludes (Reference 2, pp. 150-151):

> Tests . . . show that if rubber is incorporated into asphaltic concrete as a large amount of the mixture or by a procedure allowing limited mixing time and temperature, the rubber constitutes a network or an elastic aggregate in the pavement. If rubber is to be used as a modifying agent of the asphalt cement, the method of rubberizing must accomplish a complete solution of the rubber in the asphalt cement.

Rostler adds:

> There is one way of speeding up this solution . . . you dissolve the rubber first in maltenes and then mix this maltenes solution with the asphalt, which is a solution of asphaltenes in maltenes. These two solutions will eventually mix (Reference 2, p. 201).

COMMENTS BY OTHER INVESTIGATORS

Dale Levy (Phillips Petroleum Company) has stated very succinctly one of the significant reasons that technologists have continued to use rubber in asphalt:

> Anyone who has witnessed the results of laboratory investigations of rubber in asphalt cannot help being impressed with the weird and wonderful resilient properties exhibited by specimens. These observations plus the continual development of new synthetic rubbers with greater tensile strength and elastic properties keep the potential of rubber use in pavements alive in spite of setbacks (Reference 2, p. 295).

Asphalt consultant Bob Dunning, however, expresses concern about what may too often be an uncritical acceptance of the beneficial effect of rubber: "The rubber has been added to the asphalt. A difference has been noticed and a statement has been made, 'Because this has rubber in it, it is good'" (Reference 2, p. 198).

It is impossible to assess the influence of successive studies, one upon another. It could be that, in many instances, hypothetical statements made by pioneers are simply being repeated.

The following additional excerpts and comments from Reference 2 may serve to illustrate the attitudes that prevailed during the symposium.

> If we are concerned that tailor-made asphalts, despite increased life expectancy, will cost far in excess of those in present-day

use, we should not let this fact alone stand in the way of exploratory development (G. W. Cleven, FHWA, p. 8).

Many early efforts to use rubber in asphalts proved to be unfruitful because any kind or type of rubber was added to any kind or type of asphalt, regardless of chemical compatability (Cleven, p. 11).

The backbone of studies and applications in Great Britain was the programme developed under the collaboration between the Road Research Laboratory . . . . and Natural Rubber Producers Research Association. This program was intensified in the second half of the Fifties and continued until the second half of the Sixties. The conclusion from these large-scale applications is that the advantages derived from rubber addition were definitely confirmed (C. Capitani, p. 274).

There have been instances of favorable performance and justification for use of rubber in pavement. There have also been a number of inconclusive projects (D. Levy, p. 294).

Quite small quantities of rubber produce very large changes in the properties of asphalt . . . these changes depend critically on the type, amount and method of incorporation of the rubber. . . . The maximum effect of the rubber was produced when particles of rubber were dispersed or dissolved in the asphalt to produce a gel (G. Cockbain, Natural Rubber Producers Research Association, p. 322).

It has been shown that vulcanized rubber aggregate can be used as a Strain Relieving Interlayer in the layered highway system to alleviate reflection cracks (B. M. Gallaway, Texas A & M University, p. 349).

There is too much emphasis put on skid resistance. There is very little difference in skid resistance in rubberized and non-rubberized asphalt. Just forget about skid resistance (F. Rostler, p. 245).

Conclusive evidence as to the merit of addition of rubber to road surfacing materials can only come from road experiments. The organization, execution and interpretation of road experiments is extremely complicated . . . most trials contain many factors over which little or no control can be exercised and in cases where no adequate control sections have been laid, the so-called trials are almost without value (Cockbain, pp. 337-338).

Dissolving of rubber in an asphalt is a time and temperature dependent process. As the temperature of mixing is raised, the required time is decreased. . . . There is a limit to heating time and temperature that can be applied without seriously affecting the rubber, and, of course, the asphalt. . . . Rubberizing reduces the response of the mix to compaction . . . rubberized asphalt mixtures become more rubberized and more elastic in aging (Rostler, p. 151).

> Rubberizing asphalt is an effective means of imparting enhanced elastic properties to flexible pavements (Rostler, p. 151).
>
> Using more rubber than needed to be effective is not only uneconomical but can also be . . . detrimental (Rostler, p. 145).

The working hypothesis of Farbenfabriken Bayer, a German company, was given as follows:

> a) The rubber binds firmly to itself the maltenes. This prevents the maltenes, which are so important for the general properties of the bitumen, from being lost under the action of traffic and solar radiation, and the residual binder from becoming brittle.
>
> b) The colloidally dissolved rubber confers its properties on the bitumen.
>
> c) A predominantly coarsely-dispersed, undissolved or unswelled rubber plays only a subordinate role, since in this state it is unable to confer its typical properties on the bitumen (H. Esser, Farbenfabriken Bayer, p. 236).
>
> A rubber which is to be used for the modification of bitumen must, for the major part, dissolve or swell strongly in the maltenes. Certain synthetic rubbers, e.g., nitrile rubber, which because of their chemical composition possess a high resistance to solvents or oil meet this requirement imperfectly and are therefore less suitable. Amongst those rubbers from which, because of their chemical composition, a good swelling power may be expected, the most suitable types possess a slight degree of branching or cross-linking. For this reason also, vulcanized rubber (as rubber powder obtained from ground tires, conveyor and drive belts, old shoe soles, etc.) is not suitable for the improvement of bitumen (Esser, p. 237).

A new concept in rubberizing existing pavements in place is described in Reference 2 (p. 296) by D. F. Levy, representing the Phillips Petroleum Co. (The concept is also described in Reference 6.) The Phillips Petroleum Co. patents on rubberizing asphalts have recently been purchased by Witco Chemical Co. (Golden Bear Oil Co., Bakersfield, California); but at the time of Levy's presentation, the rubberizing material was marketed by Phillips under the tradename Petroset$_{TM}$. The rubberizing material is a

Reference

6. Rostler, F. S., and White, R. M., "Fractional Components of Asphalts--Modification of the Asphaltenes Fraction," *Proceedings of the A.A.P.T.*, Vol. 39, 1970, pp. 532-559, discussion pp. 563-571.

cationic emulsion of a solution of the polymer in maltenes and is sprayed onto the existing cold, compacted pavement. The emulsion performs its function by penetrating the pavement surface, migrating through the voids, and depositing the oil phase of the emulsion on the asphalt in place. (Although previous objections to the Phillips rubberizing process, such as interference with conventional construction procedures or asphalt specifications, have been overcome, a problem remains in that the treated pavement has a potentially dangerous low frictional resistance to the skidding of vehicles for several days after the surface application.)

Levy describes the benefits of the Phillip's process as follows:

The maltenes ratio parameter has been substantiated as a means of predicting durability of pavements containing unmodified asphalts. The addition of a Solprene GEO rubber to the asphalt in situ in the form of a cationic emulsion Petroset AT, has been shown to enhance asphalt properties above those predicted from the maltenes ratio and hence produces an asphalt of greater durability than the original asphalt. In addition to the long range effects of rubberizing the asphalt pavement, more immediate results are apparent. The pavement is almost completely sealed against air and water permeability. Thus, pavement life is also enhanced by protecting the asphalt from the oxidative effects of air (oxygen) and from the damage occurring from water; i.e., stripping of the asphalt from the aggregate and damage to the pavement due to freeze thaw cycles of the moisture in the pavement.

The benefits of rubberizing with Petroset AT emulsion can be summarized as follows:

1. Small amounts of rubber, 0.75 to 1.50 percent, are highly effective, and factors (a) through (e) extrapolate to longer pavement life.

   a. Increased ductility of asphalt, particularly at low temperature.

   b. Increased elastic recovery of pavement.

   c. Increased resistance to wear.

   d. Full utilization of rubber added since there is no chance for degradation due to temperature.

   e. Increased molecular weight of asphaltenes fraction.

2. Asphalt pavement structures are essentially sealed against water and air permeation.

3. Asphalt pavement construction can proceed normally without problems of mixing, laying and compaction.

4. Normal mix times in the pug mill can be retained.

5. Asphalt suppliers need not add rubber to storage tanks.

6. The method of application is simple.

Petroset AT geotechnic emulsion is recommended for rubberizing all newly constructed asphalt cement pavements regardless of thickness. It is particularly recommended for new pavements since at this time, immediately after final compaction, the pavement will have near uniform density and contour and will be free of surface glaze. This condition will allow uniform penetration of the polymer emulsion.

If the pavement is to be treated in depth it is recommended that each lift be treated separately prior to laying the next lift. This eliminates the need for use of a tack coat between lifts. Also, to penetrate a deep pavement the calculated application rate could be excessive and cause run-off of the emulsion if the pavement is not level. In either case, use of a tack coat between lifts should be avoided, since penetration of the emulsion may be considerably retarded (Reference 2).

A paper entitled "Use of Rubber Aggregate in a Strain Relieving Interlayer for Arresting Reflection Cracking of Asphalt Pavements," prepared by B. D. La Grone, U.S. Rubber Reclaiming Co., and presented by Prof. B. M. Gallaway, Texas A & M (Reference 2, p. 341) deals with the problem of cracked pavements that continue to crack after an overlay is applied. Various combinations of ground vulcanized rubber (tires, etc.), mineral filler, and asphalt (in both cement and emulsion form) were investigated. A formulation containing approximately equal parts by volume of ground vulcanized rubber, sand, and residual asphalt in emulsion form was found to yield a waterproof material that exhibited high elongation and low air voids and, at the same time, could be placed in a thin layer. The rubber had a 1/8-inch maximum particle size and was produced from ground scrap automobile tires.

Laboratory and field tests showed that vulcanized rubber aggregate could be used as a strain-relieving interlayer (SRI) in a layered highway system to alleviate reflection cracks. A sample displayed at the symposium was composed of 30 percent asphalt volume, 33 percent rubber from reclaimed

tires, and 37 percent sand. During the discussion period, it was revealed that the SRI was not effective in overcoming effects of vertical strain, but was effective in overcoming effects of horizontal strain in pavement.

C. H. McDonald, asphalt consultant and inventor, presented a paper entitled "An Elastomer Solution for Alligator Cracking in Asphalt Pavement" (Reference 2, p. 363). This system was designed to overlay and prevent reflection of cracks induced by fatigue or flexicracking. Ground rubber from used tires was added to asphalt heated to a temperature of from 300° to 500° F. The exact nature of the time-temperature reaction has not been determined; however, McDonald states:

> It is known that there is a partial solution of the rubber accompanied by swelling of the rubber particles and absorption by them of some of the asphalt components. The net result of the reaction is a thickening of the mixture to a consistency similar to that of very thick pancake batter. . . . In actual practice, approximately 20 to 30% rubber and 80 to 65% asphalt by weight is normally used, depending on traffic and climatic conditions.

McDonald's presentation continues as follows:

> 20% to 25% of rubber by weight of the mixture is adequate where the temperature seldom drops below freezing, while 30% to 35% is used in the colder areas. Test panels employing 33% rubber have been tested under severe winter conditions in the west at elevations up to 7000 feet without developing reflection cracking over severely "alligatored" surfaces. The important points to remember are that, as the percentage of rubber in the mixture increases, the greater the elasticity of the mixture and the more the temperature susceptibility of the mixture is reduced.
>
> In the science of rubber technology, which is a very complex one and not fully understood to this date, theoretically it can be shown that ground tire rubber contains much lower percentages of elastomer as pure rubber hydrocarbons that can be obtained from other rubber products and is therefore not the most economical source of rubber hydrocarbon. However, in this process, the rubber hydrocarbons, as asphalt modifiers, are supplemented by another factor that is apparently more important in the overall elastic performance of the mixture. This is the mechanical action of the ground rubber particles performing as a completely elastic aggregate within the matrix of asphalt, modified by the dissolved rubber. This rubber aggregate appears to add more to the flexibility of the material than the actual percentage of rubber hydrocarbons modifying the asphalt.
>
> Now, all of the literature that I was able to get hold of when I started this indicated that the maximum benefit from rubbers in asphalt was obtained when you've got a complete solution of the rubber - or a near complete solution of the rubber - in the asphalt.

Therefore, the excellent performance of this material in which there was only two or three percent solution somewhat puzzled me.

A few weeks ago, Bob Dunning came over. You all know Bob Dunning of the Douglas Oil Company. He proposed a reason for this. It is very interesting and very reasonable. At this point, I would like Bob to get up and give this reason to us. Bob, are you here?

Bob Dunning: After talking with Charlie and seeing the action of this material, it reminded me of the method of which impact resistance is imparted to polystyrene. In that case into crystal grade polystyrene is added rubber, disbursed rubber and then upon impact or upon flexing that will cause a crack, the crack is propagated only a very short distance and pops the piece of rubber out of the matrix or at least stops at the matrix. Also, if you look at literature on crack propagation, one method by which to prevent the drastic cracking or complete cracking is to form many small cracks that are terminated, and thus prevents a failure of the whole matrix. Thus, the rubber by small particles are perhaps stopping propagation of cracks, which if you had it dissolved in the whole matrix would still allow a fatigue crack to creep across.

Charles McDonald: Thank you, Bob. And however this may be, the important point is that it works. It actually does. When this hot material has reached the proper degree of reactive consistency, it is applied hot to the pavement at a temperature of 325 to 460 degrees F. and in amounts ranging from 0.3 of a gallon per square yard to one gallon per square yard depending upon the severity of the condition that it is planned to correct. Immediately following the application of the asphalt-rubber mixture to the distressed pavement, cover aggregate is applied for the purpose of resisting the wear and abrasive action of traffic.

A unique property of this material is that when fully reacted, it will not pick up on the tires of moving vehicles even without application of cover material and even when the maximum applications have been used.

The material will not entirely prevent the reflection of large shrinkage cracks but will prevent the reflection of fatigue cracking when correctly formulated in the proper quantities. Its high tensile strength enables it to hold loose floating fragments of underlying pavement in position without their coming out or showing any signs of surface distress.

The first large application with modern equipment was made in the winter of 1966-1967 on the principal jet taxiway at Phoenix International Sky Harbor Airport. At one point, a spillage of this material approximately 1/2 in. to 3/4 in. in depth was made, and after sanding and cooling, was turned over to jet traffic within an hour and gave excellent service until 1970, at which time a realignment of the taxiway destroyed the application. However,

the asphalt-rubber material at the location of the spillage reacted to the last like a 1/2 in. to 3/4 in. slab of rubber under the heavy wheels of the jet airplanes. It would deflect under the load and "bounce" back to its original shape after passage of the load.

Of interest in this first large scale experiment, were observations made in regard to the oxidation and hardening properties of this material. It appears that the asphalt and rubber are mutually protective in this regard. The rubber, of course, contains antioxidants and absorbs the asphalt to some extent so this may be one factor. In any event, we actually made observations over a 3 to 4 year test period and found that a very thin oxidized film formed on the surface only of the material. This film was as thin as tissue paper, hard and slightly brittle. This apparently served as a protective barrier for below this film there was no apparent change in the properties of the asphalt-rubber material which remained as resilient, tough and functional as at the time of placement.

We have placed approximately 75,000 square yards of this material at Sky Harbor International Airport including the west 1000 feet of the main jet runway. All of this was placed over severely fatigue-cracking areas, and it has been successful in preventing any failure due to reflection cracking of the areas treated. In addition to this, street applications have been made in California, Arizona and Nevada and so far as I am aware, these applications have successfully eliminated any problem of fatigue cracking.

This material, up to its present state of development, cannot be successfully applied with conventional asphalt distributor equipment. The distributor equipment must be modified to provide adjustments for incorporating the rubber, and more powerful pumps are required for handling the more viscous material. Equipment has been developed to do this by both the batch and continuous mix process, and further refinements are in the mill.

A still further development has occurred, however, involving the use of diluents on the asphalt-rubber material that has been previously reacted in the hot process described above. The purpose of this is to reduce the viscosity so that it can be applied through conventional asphalt distributor equipment. The viscosity of the material can be reduced by the use of any one of a number of aliphatic solvents, or any other asphalt solvent. Kerosene has proven to be very effective in tests. However, naphtha, or even more exotic solvents, such as methylene chloride, can be used. The amount of solvent used would be governed by the viscosity of the mixture desired but would normally range from approximately 5% to 45% by weight of the asphalt-rubber composition. This processed material could then be applied with conventional equipment, at a relatively low temperature, in the same manner as a cutback asphalt. The subsequent loss of solvent by evaporation would leave the essentially original asphalt-rubber material in place.

It has previously been noted that properly prepared asphalt-rubber is not subject to bleeding in itself. Unlike a conventional overlay, it does not contain voids and does not migrate like asphalt but forms an impervious membrane over the surface upon which it is placed. Therefore, it has excellent possibilities for correcting slippery pavements due to "flush up" or bleeding of asphalt. Limited tests indicate that it works but more large scale tests should be undertaken. Skid resistance tests on asphalt-rubber installations show that the skid resistance is governed by the presence and character of the cover aggregate.

The following example relates only indirectly to rubberized pavements, but it bears repeating as an example of the complexity of relating cause and effect in pavement design. In order to study the effects of repetitive loading on airport pavements, the Army Corps of Engineers initiated a program of accelerated traffic test tracks in 1941 that was continued until 1954 (Reference 7). Traffic testing was conducted on existing pavements at four airfields and at 14 specially constructed test tracks. Insofar as fatigue is concerned, the repetitive loading study was inconclusive. It was found to be practically impossible to isolate the factors that induce stress in the pavement and that affect pavement performance.

Reference

7. Hutchinson, R. L., *Basis of Rigid Pavement Design in Military Airfields*, Miscellaneous Paper No. 5-7, Army Corps of Engineers, Ohio River Division Laboratories, Cincinnati, Ohio, May 1966.

SECTION III

SUMMARIES OF SELECTED LITERATURE

In 1971, F. S. Rostler prepared *An Annotated Bibliography on Use of Rubber in Asphalt Pavement* (Reference 8) for the Federal Highway Administration. In the forward to the bibliography, Rostler makes the following comments:

> Considerable effort has gone into research studies and experimental construction to demonstrate the advantages of using rubber in highway asphalts. In almost every case laboratory tests indicated that significant improvements might be expected from the use of rubber. However, most early field tests failed to provide sufficient evidence of improved performance to justify the added costs of rubber (pp. 1-2).
>
> Analysis of the information compiled leads to the conclusion that the facts reported in the literature support the claims made by various investigators that the addition of rubber to asphalt changes asphalt properties in a theoretically desirable direction, but the test methods used and the field tests performed are not sufficiently convincing evidence to recommend large scale use in a routine manner (pp. 4-5).
>
> Comparisons of straight asphalt cement with rubberized asphalts favor the latter in a manner out of proportion to performance (p. 5).
>
> It appears probable that the most advantageous use of rubberized asphalts will be to upgrade borderline materials or permit more economical designs (p. 6).

To give the reader a feeling for the rather broad range of existing views on the use of asphalt-rubber, excerpts from Rostler's summaries are quoted in this section.[1]

Reference

8. Rostler, F. S., *An Annotated Bibliography on Use of Rubber in Asphalt Pavements*, Report No. FHWA-RD-72-1, Office of Research, Federal Highway Administration, Washington, D.C., May 1971.

Footnote

[1]All page numbers given in this section cite Reference 8.

"Natural Rubber Roads--A Review of Research and Experiment," *Technical Note No. 3*, The Natural Rubber Development Board, London, 1959.

. . . Summarizing laboratory findings it is stated that changes effected in asphalt have been found dependent on amount and type of rubber and on time and temperature of heating during preparation. In general, studies have shown increase in softening point and decrease in penetration, greatest when using latex or unvulcanized rubber, less when using vulcanized rubber. Sand-asphalt mixes with rubberized asphalt have been shown to exhibit decreased deformability at 45 F and greater extensibility at 0 C in tensile testing (p. 11).

D. C. Thompson (E. I. du Pont de Nemours and Co., Inc., Wilmington, Delaware), "Rubber Modifiers," *Bituminous Materials*, Arnold J. Hoiberg, Ed., Vol. 1, Chapter 9, Interscience, New York, 1964, pp. 375-414.

. . . In comparing various rubbers the author concludes that swollen rubbers that remain suspended in bitumen are most useful, while rubbers which dissolve are not very effective modifiers (p. 13).

P. D. Thompson, "The Use of Natural Rubber in Road Surfacings," *N.R.P.R.A. Technical Bulletin No. 9*, The Natural Rubber Producers' Research Association, London, 1964.

To insure the maximum advantage [in asphalt], rubber should be fully dissolved . . . . A method for determining both total and effective rubber is presented (p. 14).

Kenneth Allison (Engineering Editor), "Those Amazing Rubber Roads," *Rubber World*, Vol. 155, No. 6, pp. 47-52 and Vol. 156, No. 1, pp. 91-94, 96, 98, 100, 102, 104, 106, March and April 1967.

. . . It is known today that only a portion of the total rubber previously used in rubberizing was "effective" rubber and that a surplus of rubber added is actually detrimental. Methods are now available by which all rubber incorporated becomes "effective" rubber (p. 15).

L. E. Gregg (Kentucky Department of Highways) and W. H. Alcoke (University of Kentucky), "Investigations of Rubber Additives in Asphalt Paving Mixtures," *Proceedings A.A.P.T.*, Vol. 23, 1954, pp. 28-60; discussion pp. 60-63.

. . . Microscopic examination of dispersion of the rubber in the binder and performance in fatigue testing led the authors to the conclusion that greatest strength is obtained when the rubber is present as a fibrous structure with gradation of strands from coarse to fine (p. 19).

R. Bugeon (Paris, France), "Der Zusatz von Latex zu Bitumenemulsionen" (The Addition of Latex to Bituminous Emulsions), *Bitumen--Teere--Asphalt--Peche*, Vol. 5, No. 1, January 1954, pp. 3-9.

> . . . It is concluded that a latex of 60% solids is suitable for admixing with bituminous emulsions, while a latex of 40% solids is not (p. 19).

Richard H. Lewis and J. York Welborn (Physical Research Branch, Bureau of Public Roads), "The Effect of Various Rubbers on the Properties of Petroleum Asphalts," *Public Roads*, Vol. 28, No. 4, October 1954, pp. 64-89.

> This paper is one of two companion articles reporting the most extensive laboratory study made to date on the effects of several rubbers on the properties of asphalts. . . . [Amount of rubber ranged from 5% dispersion to 10% dispersion in asphalt.] The rubbers differed in the extent they modified asphalt properties, natural and unvulcanized SBR showing large changes; reclaimed, compounded natural, scrap and vulcanized SBR showing only small effect; and poly(butadiene) intermediate.
>
> . . . Microscopic examination of the blends showed that in general, natural rubber and the unvulcanized synthetic rubbers were disbursed through the asphalt, while the reclaimed, scrap and compounded rubbers and the vulcanized SBR remained, except for swelling, as discrete particles. Greatest degree of rubber dispersion corresponded with greatest change in asphalt properties. It is pointed out on the other hand that the significance of the laboratory tests cannot be established until confirmed by experimental pavements exposed to the influence of age, weather and traffic (pp. 20-22).

Harry M. Rex and Robert A. Peck (Physical Research Branch, Bureau of Public Roads), "A Laboratory Study of Rubber-Asphalt Paving Mixtures," *Public Roads*, Vol. 28, No. 4, October 1954, pp. 91-98.

> This companion study to the paper of Lewis and Welborn describes effects of rubberizing on the properties of asphalt-aggregate mixes. . . . Asphalt-aggregate mixes were prepared by two methods--predispersion of rubber in asphalt before mixing with aggregate, and adding asphalt to aggregate premixed with rubber powder.
>
> . . . Addition of rubber in powder form showed low compactability of the asphalt-aggregate mix, resulting in lower stability and higher temperature susceptibility than the control. The same lack of compactability was evident in cores from road test sections where rubber powder had been added in the same manner. However, except for reclaim mixes, the preblended rubbers and the asphalt-plasticized rubber exhibited equal or better compactability than the control, resulting in improved stability and temperature susceptibility. On oven aging stability and temperature susceptibility of the powder mixes improved somewhat. The mixes with preblended asphalt-rubber showed differing results, with only the SBR mix retaining after aging superior temperature susceptibility to the control.

None of the rubber mixes evidenced improvement in water resistance. In abrasion tests on preblended mixes on Ottawa sand, only the natural rubber was significantly superior to the control. Other rubbers tested were either equal to or inferior to the control (pp. 23-23).

Jewell R. Benson (Consulting Bituminous Engineer, Denver, Colorado), "New Concepts for Rubberized Asphalts," *Roads and Streets*, Vol. 98, No. 4, April 1955, pp. 138-142.

. . . Only rubber dispersed to a degree approaching molecular size particles can be considered as "effective rubber" and the resultant material described as "rubberized asphalt." In this form, as little as 0.1% of rubber has been found to alter asphalt properties, although effectiveness varies with the nature of the rubber used. Where rubber is present as discrete particles, it should be considered as an elastic aggregate. It is suggested that for a practical material effective rubber content should not exceed 3%, since higher amounts interfere with construction practices. It is suggested that advantages of rubberized asphalt are most apparent when used in surface treatments or seal coats, since the improvement imparted by rubber to the binder will effect only marginal improvement if used in original construction of a well-designed pavement.

Properties of asphalt most significantly altered by "effective rubber" are described as toughness and tenacity. A test method is presented for determining these properties by pulling a hemispherical metal ball of specified size from an asphalt specimen of specified volume at specified rate.

. . . Caution is advised to avoid heating the materials above 375° F either in testing or use to prevent possible depolymerization of the rubber (pp. 24-25).

Jewell R. Benson (Consulting Bituminous Engineer, Denver, Colorado), "The Present Status of Rubberized Asphalts for Highways," *Roads and Engineering Construction*, Vol. 93, No. 8, August 1955, pp. 78, 80, 82, 84, 108, 110, 112.

. . . Surface treatments and seal coats are considered to be the best proving ground for rubberized asphalts. Hot-mix asphalt concrete pavements are today so well designed that rubberizing plays a minor role in total performance observable in a short period of time, unless there are marked deficiencies in materials, design or construction. Rubberized asphalts in cut-backs . . . make poor prime coats and penetrating materials. . . . The two main requirements for high-quality rubberized asphalts are (1) composition containing the minimum amount of rubber to produce the desired properties, and (2) that the rubber must be compatible with the asphalt and dispersed to essentially the point of solution (p. 26).

H. A. W. Nijveld, H. C. J. De Decker, and H. A. O. W. Geesink (Rubber-Stichting, Delft, Netherlands), "Mechanical and Rheological Measurements on Rubber Bitumen and Rubber Asphalt Mixtures," *Proceedings of the Fourth World Petroleum Congress, Section VI/A*, Paper 1, Rome, Italy, 1956, pp. 1-8, discussion pp. 8-9.

> . . . Undissolved rubber produces undesirable elastic effects [in rubber-asphalt] (p. 27).

K. Nachtigall, and T. G. F. Schoon (Indonesian Rubber Research Institute, Bogor, Indonesia), "Mikroskopische Untersuchungen von Kautschukdispersionen in Bitumen" (Microscopic Examination of Rubber Dispersions in Asphalt), *Kolloid-Zeitschrift*, Vol. 156, No. 2, 1958, pp. 122-132.

> . . . Rubber dispersions in asphalt are spherical agglomerates of rubber molecules, the size of the agglomerates depending on the nature of the asphalt, particularly its ability to swell the rubber. Admixing of rubber at temperatures below 250° C [482° F] does not depolymerize the rubber and does not change the microscopic structure; mixing at temperatures above 250° C [482° F] depolymerizes the rubber and the microscopic picture does not show any undispersed rubber particles. Rubber is considered embedded in a system of gelling and solvating liquids (pp. 33-34).

Chuzo Itakura and Teruo Sugawara (Hokkaido University, Sapporo, Hokkaido, Japan), "Some Characteristics of Rubber-Blended Asphalt and Its Mixtures at Low Temperatures," *Proceedings A.A.P.T.*, Vol. 28, 1959, pp. 385-412.

> . . . Effect of rubber on temperature sensitivity calculated from the penetration values gave contradictory results (p. 35).

James M. Rice (Director, Road Research, Natural Rubber Bureau), "Field and Laboratory Experience with Natural Rubber as an Additive for Asphalts," Paper presented at The Asphalt Institute Symposium on Rubber in Asphalt, Chicago, Illinois, March 24, 1960.

> . . . The majority of those field applications of rubberized asphalts where objective evaluation was available had provided improvements in the form of better retention of aggregate, less bleeding and more uniformity. Benefits were consistently noted where rubber was added as latex; in most of the projects where no advantages were noted, the rubber was added in powder form (p. 41).

W. Szatkowski (Road Research Laboratory, Harmondsworth, Middx., Great Britain), "Estimation of the Total and Effective Rubber Contents of Rubber-Bitumens," *J. Appl. Chem.*, Vol. 13, 1963, pp. 64-69.

> . . . Effective rubber is expressed as the concentration of a standard rubber which if present in the asphalt would give the same specific viscosity in benzene as the sample. . . . Effects are shown graphically of prolonged heating at temperatures up to 200° C on both effective and total rubber content,

which results are recommended as a guide to selecting the duration of heating permissible at any temperature without destroying effective rubber. . . . The effective rubber content of binders may be much less than intended due to overheating (pp. 45-46).

Heinz Esser, "Kautschukvergutetes Bitumen" (Rubber-Improved Bitumen), *Bitumen--Teere--Asphalte--Peeche und verwandte Stoffe*, Vol. 17, No. 9., September 1966, pp. 319-326, 328.

. . . Crosslinked polymers and vulcanized rubbers, particularly ground scrap rubber are unsuitable. . . . Poly(chloroprene) latices are superior to all other types of rubber (p. 49).

John Albert Alexander, "Effects of Rubber Additives on Properties of Asphaltic Materials," Master's thesis carried out under supervision of F. Moavenzadeh, Massachusetts Institute of Technology, Cambridge, Massachusetts, August 1968.

. . . Rubberized asphalt is considered to be a type of composite containing a rubber-asphalt second phase which functions as a crack inhibitor, explaining the toughness in the rubber-modified asphalt (p. 52).

Fritz S. Rostler and Richard M. White (Materials Research and Development, Inc., Oakland, California), "Fractional Components of Asphalts--Modification of the Asphaltenes Fraction," *Proceedings A.A.P.T.*, Vol. 39, 1970, pp. 532-559, discussion, pp. 563-571.

A new concept is described by which the pavement is rubberized rather than the asphalt or the asphalt mix. The asphalt contained in the pavement is rubberized by adding an elastomeric material, a terminal block butadiene; styrene copolymer, in small amounts (0.5 to 1.5%) which becomes, by analysis, part of the asphaltenes fraction. The polymer is a rubber of high tensile strength (4000 psi) in the unvulcanized stage. The rubber is incorporated into the pavement in the form of a cationic emulsion of a solution of the polymer in maltenes. Advantages of polymer addition are demonstrated in terms of improvement measured by the pellet abrasion tests run at 77° and 50° F on asphalts of all durability ranges. The method of adding the polymer by application in emulsion form to compacted asphalt concrete eliminates previous objections to rubberizing by not interfering with conventional construction procedures or asphalt specifications. The emulsion used penetrated into several inches of the pavement.

. . . The mechanics of the rubberizing is explained as a delayed action phenomenon in which the rubber combines with the asphalt after maximum density attainable by compaction has been achieved. Compatibility of the polymer with representatives of all asphalts manufactured at the present time and the degree of dispersion achieved is shown in photomicrographs (p. 55).

John L. McRae (U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi), and B. D. LaGrone (U.S. Rubber Reclaiming Co., Inc.), "Effect of a Modified Reclaimed Rubber and Ground Vulcanized Rubber on the Physical Properties of Bituminous Pavements as Evaluated by the Gyratory Testing Machines," Paper presented at 50th Annual Meeting of the Highway Research Board, National Research Council, National Academy of Sciences, National Academy of Engineering, Washington, D.C., January 1971.

> . . . The authors conclude that reclaimed rubber or ground scrap can enhance the performance of pavements if total binder is 0.5 to 1.0% above that found best for straight asphalt [without rubber] (p. 56).

SECTION IV

CONTEMPORARY USE OF RUBBER-ASPHALT

INTRODUCTION

D. C. Thompson (Reference 1) cites a great many agencies that have been involved in research, development, and promotional efforts aimed at improving roads by adding elastomeric polymers to asphalt compositions. In the United States today, only five groups are known to be actively producing and marketing asphalt-rubber for traffic ways:

1. Sahuaro Petroleum and Asphalt Company
   731 North 19th Avenue, P.O. Box 6536
   Phoenix, Arizona 85005
2. Arizona Refining Company (ARCO)
   P.O. Box 1453
   Phoenix, Arizona 85001
3. Husky Oil Company
   P.O. Box 380
   Cody, Wyoming
4. Witco Chemical, Golden Bear Division
   P.O. Box 378
   Bakersfield, California
5. Textile Rubber and Chemical Co., Inc., Western Division (TR & C)
   14241 E. Alondra Boulevard
   La Mirada, California 90638

SAHUARO PROCESS

The Sahuaro Petroleum and Asphalt Company markets an asphalt-rubber composed of ground rubber tire particles blended with a heated penetration-grade asphalt. The Atlos Rubber Company, Los Angeles, California, holds the licensing rights to the patent on this asphalt-rubber composition. The process was developed by Charles H. McDonald, and Robert Winters of Atlos Company is listed as a coinventor in Patent No. 3,919,148, dated November 11, 1975.

This patent references the invention of an elastomeric pavement composition by McDonald and John P. Harmon; McDonald is also the inventor listed for Patent No. 3,891,585, dated June 24, 1975, for a similar material.

Probably the best description of the Sahuaro process is given in Reference 9, summarized below. The general description of the material is the same for surface sealing, interlayer, and crack and joint filler.

Ground rubber tire particles passing the No. 16 sieve and retained on the No. 25 sieve are blended with penetration-grade asphalt heated to 300° to 450° F. After about an hour at this temperature range, a reaction takes place between the rubber and the asphalt. The precise nature of this reaction remains a mystery. It is believed that a limited portion of each discrete rubber particle goes into solution and that the remainder of each particle is swollen and behaves like an elastic aggregate. The elastic quality of the mixture at normal ambient temperatures is probably caused by the mechanical action of the undissolved rubber particles performing as a completely elastic aggregate within the asphalt, which is modified by the dissolved rubber. These undissolved rubber particles also serve as units of elastic interference to the propagation of cracking.

In order to distribute the hot asphalt-rubber mix, two problems with conventional distributors had to be overcome. The hot mixture is highly viscous, and the rubber particles tend to precipitate. A diluent (usually kerosene) in the amount of approximately 6 percent by volume added to the blended asphalt-rubber temporarily reduces the viscosity to permit spraying from the No. 5 distributor nozzles. Modified distributor trucks have a screw agitator that runs the entire length inside the mixing and holding tank to keep the rubber in suspension.

The following construction procedure is used. The pavement to be sealed is patched, cleaned, and tacked with a diluted SS-1H emulsion the day before

Reference

9. Olsen, Robert E., *Rubber-Asphalt Binder for Seal-Coat Construction*, Implementation Package 73-1, Federal Highway Administration, Office of Development, Washington, D.C., 1973.

construction is scheduled. It is also recommended that cracks and joints be filled prior to application of the asphalt-rubber membrane. The asphalt (120/150 pen. grade) is heated in a modified distributor truck to a minimum temperature of 350° F (the temperature must not exceed 400° F). Ground tire tread rubber, 95 percent passing the No. 16 sieve and not more than 10 percent passing the No. 25 sieve, is added to the hot asphalt in the proportion 75 percent asphalt to 25 percent rubber. As the rubber is added, the temperature of the mix is reduced and the viscosity is increased. After a mixing time of up to an hour, the reaction between the rubber and asphalt is completed. The diluent is then added and mixed. The material is applied to the pavement at the rate of 0.4 to 1.0 gallon per square yard.

Immediately after the binder has been applied, 3/8-inch nominal size cover stone is applied at a rate of 38 pounds per square yard. It is recommended that the stone be heated to about 300° F and precoated with 0.3- to 0.5-percent penetration-grade asphalt. Precoating eliminates any dust nuisance and ensures a better bond between binder and stone. It is recommended that the cover stone be embedded at one-half its depth to ensure retention in service. The cover stone is rolled with at least three coverages by pneumatic rollers carrying a minimum of 5,000 pounds per wheel at a tire pressure of 100 lb/in^2. If the stone is not then at least 50 percent embedded, an asphalt fog seal is applied to ensure this minimum degree of embedment.

The joint and crack filling operation is normally accomplished using special equipment developed by Crafco of Phoenix, Arizona. The equipment incorporates augers for mixing the highly viscous material. A standard joint-filling rig can also be used. The mixture is identical to that for the Sahuaro process, except that no diluent is used in this application of asphalt-rubber. The crack is routed to a uniform cross-section, and the material is pumped into the opening. The material does not completely fill the crack, but bridges the opening to an unknown depth. This operation apparently works best for asphaltic concrete pavements. The routing procedure can be very damaging to portland cement concrete.

Sahuaro claims the following benefits for the asphalt-rubber membrane (SAM) type of construction (Reference 9):

1. Prevents reflection cracking from the substrate pavement because of its flexibility and the interlaced particles of rubber discourage the propagation of cracks. It is to be noted, however, that seal coat construction is not a solution to all types of bituminous concrete failures.

2. Because the asphalt-rubber composition is waterproof, the moisture in the subgrade becomes stabilized and thus reduces the tendency for localized failures.

3. The temperature susceptibility of the binder is reduced, thus reducing or eliminating the tendency of the binder to bleed in hot weather or crack because of shrinkage or flexure during cold weather.

4. This construction procedure provides a means to effectively maintain a cracked or distressed pavement without increasing the profile height of the pavement; thus height of drainage curbs can be maintained without interference.

5. Rubber-asphalt seal coat pavements have been in service for 5 years in the City of Phoenix. The pavement surfaces are presently in excellent condition and a 10-year service life is forecast.

6. The use of ground tire rubber as a component in the binder is an excellent means of using waste material. It would appear that an inexhaustible supply of rubber is available since we as a nation are presently discarding about 100 million tires a year.

The cost of asphalt-rubber seal construction in Phoenix, Arizona, has ranged from 50 to 70 cents per square yard. Currently (1978), the price probably is closer to $1.25 per square yard including the cost of traffic control, cover stone, preheating and precoating of cover stone for chip seals, asphalt-rubber binder, kerosene additive, placing, and rolling. The cost of alternative treatments that eliminate fatigue or elastic-type distress is much higher because the pavement structure must be strengthened by a bituminous concrete overlay to a point at which excessive deflections are eliminated. This process is not generally feasible in urban areas, where curb height and drainage must be maintained. Reconstruction becomes costly and is a great inconvenience to traffic.

The major disadvantage to the Sahuaro process is the necessity of using the modified distributor truck. This piece of equipment costs approximately

$150,000 and is not currently for sale. Therefore, the material can be applied only by Sahuaro personnel.

Appendix A of this report contains suggested specifications for the Hot Asphalt-Rubber Seal Treatment (SAM), issued as a guide by Sahuaro Petroleum Company. An interlayer would require essentially the same specifications as those for a seal coat. Joint-filling material would also be the same except that the rock chips would not be used. The literature indicates that the material can also be effectively used as a subgrade sealer and pond liner.

ARCO PROCESS

The ARCO process is described in Reference 10, where the Sahuaro process is also examined critically. The patent states: "We have now discovered a novel technique by which all of the foregoing problems [of the Sahuaro process] can be avoided or at least substantially alleviated." The information presented in the patent is summarized below.

In the ARCO procedure, the base asphalt stock is first modified by blending it at elevated temperatures with a minor proportion of a heavy, high-boiling, highly aromatic, high flash-point mineral oil solvent. By this method, a base stock is formed to which the rubber component, in granulated and powdered form, is then added. The resulting mixture is then heated with agitation at about 300° to 450° F for about 0.5 to 2 hours to obtain a homogeneous dispersion or solution of rubber in the base stock. Under normal conditions the resulting mixture presents no fire hazard or atmospheric pollution problems. At temperatures above about 325° F, it remains a fluid, of spreadable consistency, for periods of at least 12 hours--more in most cases. The resulting mixture can be spread over a roadway using standard equipment and spraying techniques. It forms a highly adherent membrane over the roadway and generally requires no tack coat. Because of its

Reference

10. Nielsen, Donald L., and Bagley, James R., *Rubberized Asphalt Paving Composition and Use Thereof*, United States Patent No. 4,068,023, issued January 10, 1978, assigned to Union Oil Co. of Los Angeles.

relatively nonviscous consistency, cracks are filled and sealed rather than bridged over. No difficulty is encountered in obtaining an even, smooth spray pattern from the asphalt distributor bar for membranes ranging in thickness from 1/16 to 1/4 inch.

It has also been found that the added high-boiling solvent substantially increases the life, as well as the cold temperature characteristics and durability, of pavement constructions made from the resulting asphalt-rubber compositions. It was found, however, that when the ground rubber stock employed was composed exclusively of devulcanized or synthetic rubber, the cooled membranes were somewhat lacking in toughness and resiliency. But it was learned that this deficiency could be remedied by including in the rubber stock a substantial proportion of vulcanized, ground, reclaimed natural rubber. Road testing conducted to date indicates that suitably compounded and applied membranes retain their toughness and resiliency over extended periods of time, in a manner similar to the membranes described in the patents of McDonald, Winters and others.

Asphalts that may be used in the ARCO process include any of the well known bituminous materials previously used in the paving art, such as natural asphalts or those derived from petroleum refining (e.g., by vacuum distillation, solvent refining, steam refining with or without air blowing, and the like). Those skilled in the art will readily understand that the selection of a suitable grade of asphalt depends primarily upon the climatic conditions to which the paving will be subjected: softer grades are used in cold climates and harder grades in warmer climates. At high elevations (above about 4500 feet) softer grades conforming approximately to the AR-1000 or AR-2000 specifications are preferred.

ARCO uses either natural reclaimed rubber or synthetic reclaimed rubber, supplied by the U.S. Rubber Company of Vicksburg, Mississippi. As previously indicated, the preferred mixture for the ARCO process is composed of ground, reclaimed, vulcanized natural rubber and ground, devulcanized natural or synthetic reclaimed rubber. The devulcanized reclaimed rubber component contributes to improved ductility, while the vulcanized reclaimed natural rubber (or partially devulcanized reclaimed natural rubber) contributes greatly to

adhesion, toughness, and resiliency. Vulcanized synthetic rubbers vary considerably in their rheological properties and solubilities in asphalt, but they generally contribute somewhat to toughness and resiliency. Because the vulcanized rubber components are more difficult to blend in the solvent-asphalt mixture, it is preferred that they be ground so that at least 95 percent will pass a No. 30 sieve. The devulcanized rubber component can be considerably more coarsely ground, so that 100 percent will pass the No. 10 sieve. To obtain optimum combinations of their desirable physical characteristics, the relative proportions of the basic types of ground rubbers should fall within the following preferred percentage-by-weight ranges: natural or synthetic 20 to 50, vulcanized scrap natural 25 to 45, and vulcanized scrap synthetic 20 to 40.

Examples of suitable solvent oils are those marketed by Shell Chemical Co. under the trade name "Dutrex," those marketed by Sun Oil Co. under the trade name "Sundex," and those marketed by Witco Chemical Co. under the trade names "Petroflux" and "Califlux."

The technique employed for compounding the three components is not particularly critical, the general requirements being to provide suitable means for agitating and heating the mixture at temperatures of between about 300° and 500° F, preferably about 350° to 450° F. Agitation may be provided by suitable mechanical means such as propellers, paddles, high-speed augers or the like, or by air injection through the liquid. All three components may be simultaneously admixed and brought up to the desired temperature, but the following is the preferred procedure: (1) blend the solvent oil with the asphalt and bring the homogeneous mixture up to the desired blending temperature, and (2) mix in the rubber components. Preferably, the ground natural reclaimed rubber component is added first; after thorough mixing, the devulcanized rubber is added. The time required to achieve homogeneity after the natural rubber component has been added generally ranges between about 0.5 and 2 hours, assuming good agitation. Suitable proportions of the three components in the final mixture fall within the following preferred ranges: asphalt 65 to 86, total rubber 12 to 20, and solvent oil 2 to 15 percent by weight.

For chip-seal overlays, where adhesiveness is an important consideration, rubber proportions of about 20 percent should generally be used. If the final composition is to be used as a SAMI, where the primary consideration is toughness and elasticity, preferred rubber proportions should range between about 15 to 30 percent by weight. By judicious experimentation under these precepts, an optimum proportion of the three components for any specific use can be easily developed.

Several important uses for the compositions of this invention have been developed. On old roadways that have not been too badly damaged by weathering and stress cracking, a chip-seal SAM overlayer is very effective. For this application, the pavement is first thoroughly broomed, and the hot asphalt-rubber mixture is then applied in a conventional manner from a tank spray truck. Generally from 0.5 to 1 gallon per square yard is sprayed on the pavement to provide a membrane ranging in thickness from about 1/16 to 3/16 inch. The application is usually carried out at 375° to 425° F. Rock chips are applied to the surface in the conventional manner and are immediately rolled into the membrane. These chip-seal membranes provide an effective water-proof sealant with good resiliency and wearing qualities.

Another important use, generally involving more heavily damaged roadways, lies in the area of the SAMI, a stress-relieving interface applied before the conventional asphalt concrete overlay. For this purpose, the rubber-asphalt membrane is applied substantially as described above and is then given a light coating of rock chips or sand to enable temporary traffic and construction equipment to traverse it without damaging it. The hot asphalt concrete mixture is then applied in the conventional manner in varying thicknesses. The membrane interlayer seals the concrete overlay from ground moisture and retards reflection cracking in the overlay. Membrane interlayers are particularly useful in those cases where the asphalt concrete overlay ranges in thickness from 0.5 to 4 inches, for it is with thin overlays that reflection cracking is most troublesome.

It is claimed that no crack or joint filling is needed for SAMs or SAMIs constructed under the ARCO system. This claim results from the low viscosity of the asphalt-rubber mixture during placement. The ARCO

asphalt-rubber material can, however, be used as a crack and joint filler. The literature also indicates that the asphalt-rubber membrane can be effective in sealing a pavement base from water intrusion and as a pond liner.

The current cost (1978) of the ARCO asphalt-rubber membrane is approximately $1.10 per square yard. This figure includes the cost of traffic control, cover stone, preheating and precoating of cover stone for chip seals, asphalt-rubber binder, mineral oil, placing, and rolling. Although it is currently applied by ARCO personnel, the asphalt-rubber membrane could be applied by any trained maintenance organization using an ordinary distributor.

A specification guide developed by ARCO for the SAM is contained in Appendix B. Similar specifications would be required for SAMIs.

HUSKY OIL PROCESS

The Husky Oil Co. markets a neoprene-modified asphalt for use as a chip seal or as a plant-mix seal (References 11 and 12). Neoprene-modified asphalt is produced at the refinery by adding 1- to 2-percent neoprene synthetic rubber latex to penetration-grade asphalt. The rubber is incorporated into the asphalt in a manner that completely integrates the two materials into a permanently modified asphalt. The resulting material has greater elasticity, less tendency to flow, and more stability at temperature extremes than asphalt alone. This asphalt-rubber may be used as a conventional penetration asphalt or may be combined with naphtha to form a rapid-curing cutback grade. Neoprene-modified asphalts have proven highly suitable for use in chip-seal coats and plant-mix seals.

References

11. *Neoprene Modified Asphalt*, E. I. du Pont de Nemours and Co., Inc., commercial brochure, Wilmington, Delaware.

12. *Smooth Way Through Rugged Wilderness*, E. I. du Pont de Nemours and Co., Inc., commercial brochure, reprinted from *du Pont Magazine*, January-February 1972.

Neoprene-modified penetration asphalts are available in grades 85 to 100 and 120 to 150. Rapid-curing cutback asphalts containing neoprene are available in grades RC-800 and RC-3000. Penetration and cutback grades of neoprene-modified asphalt are used in the following road surfacing products:

1. Seal coat: The asphalt is applied by distributor in liquid form. Loose aggregate is then spread on the wet asphalt.
2. Plant-mix seals: The asphalt and aggregate are prepared in a homogeneous mix and applied by paving machine to the road surface.

The following advantages are claimed for the material:

1. Easily applied with standard equipment.
2. Can be laid over all base materials.
3. Good immediate chip retention; less "throwing" of aggregate and asphalt.
4. Good long-term chip retention especially at turns.
5. Accepts high volume of chips; allows thicker aggregate layer.
6. High aggregate retention provides good wear and skid resistance and may improve resistance to hydroplaning.
7. High probability of installation success.
8. Surface provides good light reflectivity.
9. Does not "bleed" to surface.
10. Accepts large-sized aggregate.

Basic asphalt properties improved with neoprene include the following:

1. Resistance to aging, long-term elasticity.
2. Strength, tenacity and toughness.
3. Low- and high-temperature stability.
4. Resistance to "flow" and "runoff."
5. Application consistency.

The neoprene polymer is made by Du Pont's Elastomer Chemicals Department. The neoprene-modified asphalt described here is manufactured by firms that are familiar with neoprene and have developed manufacturing processes for incorporating it into asphalt. The Husky Oil Co. makes no claims for its product as a SAMI, and the material apparently has not been used for this purpose.

GOLDEN BEAR OIL COMPANY PROCESS

Although, as previously indicated, the Golden Bear Oil Co. has acquired certain patents formerly held by the Phillips Petroleum Co., the exact type of asphalt-rubber product that Golden Bear will manufacture is not yet known.

TEXTILE RUBBER AND CHEMICAL COMPANY PROCESS

In the spring of 1976, Goodyear Tire and Rubber Co. discontinued the use of the term Pliopave. Textile Rubber and Chemical Co. (TR & C) had distributed Pliopave on the west coast and believed it could make a meaningful contribution to the paving industry by continuing the program. The company will continue to market Pliopave Latex under the name of ULTRAPAVE$_{TM}$.

The following information is taken from a TR & C brochure (Reference 13):

> Results obtained when "rubberizing" asphalt depend upon many factors - rate and temperature of latex introduction, length and degree of agitation, and different types of bitumen. These factors do not hinder the modification process and results but they must be recognized.
>
> ULTRAPAVE rubber latices are particles of unvulcanized synthetic rubber in a water emulsion system. The rubber particles are extremely small and uniform when in latex form. A very high surface area is thus exposed to the bitumen during mixing and the physical dispersion of rubber is very rapid and thorough.
>
> ULTRAPAVE-70, is an anionic styrene-butadiene latex intended primarily for asphalt cements and anionic emulsions.
>
> ULTRAPAVE-65, is a cationic styrene-butadiene latex for cationic asphalt emulsions. This type of modified asphalt permits use of a wider range of aggregates, and exhibits rapid initial set when applied. Sudden rains will have less (adverse) effect than with anionic asphalts.

Reference

13. *ULTRAPAVE--Types and Properties*, commercial brochure, Textile Rubber and Chemical Co. Inc., La Mirada, California.

Almost all the applications for asphalt emulsions fall within the range of 1 to 3% rubber modification. Normal use requires about 2% rubber. One percent rubber will noticeably increase the tackiness and stringiness of emulsions. Two percent will be more effective in this respect and will add considerably to the toughness of the setting film of asphalt. Three percent rubber would be considered for severe applications where maximum film toughness is required.

ULTRAPAVE latex is said to improve the asphalt in the following ways:

1. Increase toughness.
2. Improve ductility at low temperatures.
3. Raises softening point, lowers penetration, and reduces temperature susceptibility.
4. Increases adhesion and tack.
5. Greatly reduces bleeding.

ULTRAPAVE is used in the following applications:

1. Seal coats with chips.
2. Slurry seals.
3. Thin lift wearing courses.
4. Tack coats.
5. Joint and crack fillers.

No special claims are made for ULTRAPAVE treated bitumen except for use in thin lift wearing courses where it is said crack reflections are at a minimum.

Apparently this material has never been used as a SAMI.

SECTION V
FIELD EXPERIENCE

SAHUARO PROCESS

According to *Engineering News Record*, for September 23, 1976, the Federal Highway Administration (FHWA) launched demonstration programs in at least seven states in 1976, with as many more expected in 1977, on the basis of the Arizona experience with the Sahuaro process. Several state highway departments have been contacted; however, none of them could offer any reports on the subject.

Charles McDonald reports that the first large application of asphalt-rubber with modern equipment was made in the winter of 1966-67 on the principal jet taxiway at Phoenix International Sky Harbor Airport (Reference 2, p. 369). The pavement gave excellent service until 1970, when a realignment of the taxiway destroyed the application. In 1973 an application was made to the 2-mile south runway. This runway was closed temporarily for emergency repairs only a day after it was opened (Reference 14). On April 21, 1973, the airlines and some private pilots complained that the newly finished runway was soft in spots and that tires were being cut by gravel. Most airlines notified the City of Phoenix that they would stop using the south runway until repairs were made. One airline maintenance worker said that rocks were sticking to the tires when planes landed. "In some cases, there was like a two-inch square of tar that was adhering to the wheel," said Don Moberly, Director of Passenger Sales for American Airlines (Reference 14). Director of City Airports William J. Ralston said there were no complaints from the airlines on Friday (April 27, 1973), when the runway was used all day after the reopening (Reference 14). Apparently, a cause of the problem was that SS1H was applied to the surface immediately after the stone chips were rolled. This application sealed in any residual diluent (kerosene). The

Reference

14. "Reopened Runway Lasts for One Day," *The Arizona Republic*, Phoenix, Sunday, April 22, 1973, Section B, p. 1.

black surface of the SS1H caused the membrane to become unusually warm; thus, it remained soft. An application of hydrated lime whitened the surface and caused it to reflect, rather than radiate, solar heat. The resulting cooler membrane then stabilized.

In 1976 a town in New Mexico experienced a problem similar to that reported from Phoenix (Reference 15):

> The material called 'Overflex' is a mixture of 75 percent paving asphalt and 25 percent ground rubber. . . . The mixture is heated to 400 degrees (F) and sprayed on the old street surface. Precoated aggregate is then rolled into the asphalt-rubber mixture to complete the resurfacing.

This material was placed in late September and by early October was coming up almost as quickly as it was put down. "'About the only good thing that has come out of it is a stockpile of free chips for the Village,' said John Hine, Village Manager."

The minimum desirable temperature for the spreading operation is 50° F and rising. During construction, a light snow began to fall. Apparently, the chips did not stick because (1) chips were not precoated, (2) chips were chilled, (3) the asphalt-rubber seal chilled, and (4) effective rolling of chips was not accomplished. According to Lansdon (Reference 16), embedment of chips is impossible after the mixture has cooled. The following spring, the asphalt-rubber was scraped off and a conventional seal coat was applied.

Another problem was encountered in 1977 with a chip seal on Interstate 80, about 10 miles east of Sparks, Nevada. Reflective cracking, bleeding, and dislocation of stone chips constituted the problem. Existent cracks had been filled with Petrolastic (not desired by Sahuaro), which melted and bled

References

15. "Sudderth 'Paving' Plagues Town, NM Road Officials," *Ruidoso News*, Ruidoso, New Mexico, December 9, 1976.

16. Lansdon, H. G., "Construction Techniques of Placement of Asphalt-Rubber Membranes," *Proceedings of the 13th Paving Conference*, Civil Engineering Department, University of New Mexico, Albuquerque, 1977.

when the hot asphalt-rubber was applied. Sahuaro would have preferred filling the cracks with asphalt-rubber and, in addition, had desired to make transverse saw cuts at 30-foot intervals to control further thermal cracking.

The Sahuaro asphalt-rubber product has been placed on runways of several Naval Air Stations (NAS). The following occurrence at the NAS in Fallon, Nevada is described in Reference 17:

> 10 months after the seal coat was applied to Runway 7-25, 77 to 87 percent of the existent cracks had reflected through the seal coat. The reflected cracks were much narrower than the original cracks. This may be attributable, in part, to the fact that the original pavement cracks were filled before the pavement was sealcoated, and in part to the crack-reflection - resistance of the seal coat. Subsequent inspections have shown increased reflection cracks and a general widening of the cracks.
>
> All of the seal coat installations (except recent ones at NPTR [naval parachute test range] El Centro) . . . experienced varying degrees of problems with loose aggregate. The most severe complaints were found at NAS Miramar. . . . Daily sweeping was required to remove loose aggregate from the runway.

At the NPTR in El Centro, California, ". . . the majority of cracking was fatigue type pattern cracking with a few longitudinal construction joint cracks . . . reflection cracks began to appear after the seal coats were 6-13 months old" (Reference 17).

The total analysis of problems at the NAS facilities resulted in the conclusion that the asphalt-rubber seal coat performed about as well as 2 inches of asphaltic concrete, in terms of percentages of cracking, when compared to control sections laid elsewhere by the Arizona Department of Transportation (Reference 17).

In mid-December 1976, an asphalt-rubber seal coat was applied on Runway 8-26 at the Marine Corps Air Station, Yuma, Arizona. The binder consisted of 75-percent AR-1000 asphalt and 25-percent ground tire rubber, to which precoated aggregate chips were applied. In mid-April 1977, the seal coat was reported to be very soft and was easily displaced by vehicle wheels. At

Reference

17. Brownie, R. B., *Evaluation of Rubber-Asphalt Binder for Seal Coating Asphaltic Concrete*, TM No. M-53-76-5, Naval Facilities Engineering Command, Western Division, Port Hueneme, California, August 1976.

the request of the officer in charge of construction, the Soils and Pavements Division of the Civil Engineering Laboratory, CBS, Port Hueneme, California, analyzed a sample of the seal coat. After a fairly comprehensive analysis, it was concluded that the following were possible causes for the continued softness of the asphalt-rubber on the runway[1]:

1. Insufficient heating and mixing during construction to allow the full reaction between asphalt and rubber to occur.
2. Use of AR-1000 instead of the originally specified AR-2000 asphalt in the expected high ambient temperatures at Yuma.

Runway 8-26 has been condemned for military traffic, since the asphalt-rubber was unduly soft and tender as of July 1978. However, in November 1977, a similar asphalt-rubber chip seal was completed on Runway 17-35. This has proved so far to be an excellent application.

On the basis of the findings noted in Reference 17, the commander of the Naval Facilities Engineering Command made the following statements in a letter dated January 26, 1977:

> This Headquarters re-emphasizes the criteria of [NAVFAC DM-21, Airfield Pavements] discouraging the use of chip seals on airfield pavements. In addition, the cost-effectiveness of the rubberized-asphalt type of seal is questionable, and further use of this material is not recommended until such time as longer-term performance data is available.

The letter contains additional pertinent information:

> Rubber-asphalt seal coats are effective in preventing the reflection of fatigue (pattern) type cracks but do not retard transverse and longitudinal shrinkage cracking. NAS Fallon has experienced nearly 100% crack reflection in a two year period. Two more recent installations experienced loose aggregate and interference with aircraft operations have resulted. In all cases, extensive sweeping has been required to remove loose aggregate and stabilize the seal coat. Of greater concern, however, is the report of NAS Miramar . . . . which states that the chip seal constructed in 1974 is 'breaking down' and creating a new loose aggregate problem.

In the situations described above, the asphalt-rubber was placed under adverse conditions, which probably accounts for the poor performance of the material.

Footnote

[1]Personal communication, 1978.

Two notable instances of very successful applications are Luke AFB, Arizona, and Colorado Springs Municipal Airport, Colorado. Luke AFB has a runway shoulder with an asphalt-rubber chip seal that was placed over a very badly cracked pavement. The chip seal has been in place for approximately five years with no reflective cracking now evident. A second application of a SAMI on a taxiway at Luke AFB is only two years old but shows no signs of reflective cracking. The first Colorado Springs application was a chip seal on a primary runway that carries general aviation, commercial, and military aircraft. The material was applied in 1974, and the performance has been excellent to date. Another runway was treated in June 1978, which indicates satisfaction with the 1974 application.

Several other applications of asphalt-rubber SAMIs are currently under evaluation. None of them has been in service long enough to provide any definitive data, although they seem to be performing well.

In a report on the state of the art (Reference 18), Morris and McDonald present the following summary statement:

> When placed as a seal coat, it acts as a stress absorbing membrane (SAM), and the system controls reflection of fatigue cracks (alligator or chicken wire crack pattern) and is an effective alternate to a major overlay or reconstruction. When placed as a stress absorbing membrane interlayer (SAMI), the system effectively controls reflection of all cracks.

H. G. Lansdon has provided some valuable observations (Reference 16):

> As with any new product or procedure, there were many problems to be resolved and some of these early asphalt-rubber seal coats looked like disasters. In spite of these problems (and the appearance), these early experimental sections are generally still performing excellently today. . . . The asphalt-rubber membrane when placed as an interlayer (SAMI), will virtually eliminate the reflection of all cracking. . . . The first thing we have learned . . . is that this type of seal should be used only where it will function properly and at a cost equal to or lower than other adequate solutions. Often, a new product

Reference

18. Morris, Gene R., and McDonald, Charles H., *Asphalt-Rubber Stress-Absorbing Membranes: Field Performance and State of the Art*, Transportation Research Record No. 595, Transportation Research Board, National Academy of Sciences, Washington, D.C., 1976, p. 52.

is offered which has many good attributes. Engineers . . . are hesitant to use these (new) products without being reasonably sure of success. If tests prove successful, they sometimes think they have found the answer to all their prayers and use the product in areas where it does not function properly. Some then conclude the product is worthless, while, in fact, it may be a great asset when used properly. This is true in the case of the asphalt-rubber seal coat.

ARCO PROCESS

The ARCO process has been in use for only about three years, too short a time to allow for a sound evaluation. Some ARCO-related literature and correspondence indicates that the ARCO process is performing as well as the Sahuaro process for the same initial time period. The ARCO process has been used for SAMs and SAMIs in South Dakota, Washington, New York, and Colorado, as well as Arizona; however, reports from states other than Arizona have not become available to the writers.

COMPARATIVE STUDIES

The Arizona Department of Transportation conducted a comparative test program on a 9-mile section of highway (Minnetonka East) located near Winslow on Interstate 40. This section had become eligible for overlay in 1967 and was selected for use in the National Experimental and Evaluation Program (NEEP) in 1970, the year the program was initiated. Federal participation was limited to a total overlay thickness of 1.25 inches of asphaltic concrete plus 0.5 inch of asphaltic concrete finish course. The Minnetonka-East section was considered an ideal choice for a thin overlay test program because valid conclusions would be available within a short period of time. Test sections were 1000 feet long by 38 feet wide. A control section (conventional standard overlay) adjacent to each test section was 500 feet long by 38 feet wide. Each control section served as a normalizing base for measurement. The Minnetonka-East test project was initially constructed to determine whether one or more of a variety of treatments could prevent or significantly reduce reflective cracking.

Final construction was completed in June 1972. Observations were reported for the period June 1972 through December 1975. Five treatments, the second of which was asphalt-rubber, were found to have significantly reduced reflective cracking. Results are shown in Table 1. It may be noted that the one seal coat of rubberized asphalt performed much better than did its corresponding standard test section. The report noted that asphalt-rubber interlays (Sahuaro) used as membrane seal coats should be used with stone chips to provide direct transfer of vertical loads (Reference 19).

In west central Colorado, experimental sections to reduce reflective cracking in bituminous overlays were included in the design of Project I 70-1(13). This project was part of the NEEP program and is located between Clifton and Cameo. Construction of test sections was completed in October 1971. Each treatment is represented by two 1000-foot-long sections, and there are two standard sections. Each section was overlaid with a 2-inch Type E asphaltic concrete pavement.

The following is the order in which the interlayer treatments fall when ranked according to average amount of reflective cracking:

Best:
1. Petromat interlayer (polypropylene fabric).
2. Slurry seal--asphalt emulsion interlayer.
3. Asphalt-rubber--neoprene rubber (producer not known).
4. Reclamite.
5. Petroset--a rubber binder.
6. Hand poured--cracks filled with asphalt emulsion.
7. Heater-scarifier with a rejuvenator.
8. Plant-mixed seal--5/8-inch Type A plant mix.
9. Squeeze seal--mixture of sand, hydrated lime, and MC-70.
10. Standard.

Further details may be found in Reference 20.

References

19. Way, George B., *Prevention of Reflective Cracking in Arizona Minnetonka-East (A Case Study)*, Report No. FHWA-AZ-HPR-224, United States Department of Transportation, Federal Highway Administration, Washington, D.C., May 1976.

20. Donnelly, Dennis, McCabe, Phillip, and Swanson, Herbert, *Reflection Cracking in Bituminous Overlays*, Report No. FHWA-CO-RD-76-6, Federal Highway Administration, Washington, D.C., December 1976.

TABLE 1. MINNETONKA-EAST TEST SECTION RATINGS[a]

Treatment and Test Section (T.S.) Designation	Percent of Reflective Cracking Appearing by 1975
1-1/4-inch AC Overlay and 1/2-inch ACFC	
1. Heater Scarification with Petroset	3
2. Asphalt Rubber Under ACFC	4
3. Fiberglass	5
4. Heat Scarification with Reclamite	6
5. 200/300 Penetration	8
6. Petromat	12
7. Petroset in Cracks	12
8. Asbestos	13
9. 120/150 Penetration LA Basin	14
10. Emulsion Treated AC	14
11. Reclamite Flush	15
12. Petroset Flush	16
13. Control Sections	17
14. 120/150 Penetration Four Corners	18
15. Reclamite in Cracks	20
16. 40/50 Penetration LA Basin	20
2-inch AC, No ACFC	
Rubberized asphalt seal coat	19
2-inch AC no ACFC	64

[a]Adapted from Reference 19.

The Waterways Experiment Station (WES) in Vicksburg, Mississippi, is cooperating with the Army Forces Command Office at Fort McPherson, Georgia, on a project to evaluate the effectiveness of asphalt-rubber membranes in preventing reflective cracking on roadways and runways. Asphalt-rubber membranes (both ARCO and Sahuaro) were applied at Fort Stewart, Georgia; Fort Lewis, Washington; and Fort Devens, Massachusetts, in the fall of 1977 and at Fort Carson, Colorado, in the summer of 1978. These projects are being monitored by WES. It will take several years to completely evaluate the performance of these asphalt-rubber membranes.

CONTROLLING THE PRODUCT

Both ARCO and Sahuaro maintain laboratories and regularly conduct tests of various kinds on their asphalt-rubber formulations. Insofar as the writers are aware, no quality control tests, other than particle-size analysis, are performed on the rubber. For any tests on the end product to be meaningful, it would appear that tests to identify the rubber and to determine its properties are as important as tests to identify the type and the quality of the asphalt.

Methods are available for identifying asphalts (Reference 21). When sufficient information becomes available in the asphalt data bank, even blends of asphalt can be identified and their performance predicted. The asphalt data bank consists of individual file cards (similar to IBM cards) on asphalts previously studied and described in the literature. (Data-bank cards may be purchased from the following address: Chief, Materials Division, HRS-20, Office of Research, Federal Highway Administration, Washington, D.C. 20590.)

Reference

21. Rostler, F. S., and Rostler, K. S., *Fingerprinting of Highway Asphalts: A Method for Cataloging and Identifying Asphalts*, Report No. FHWA-RD-72-18, Federal Highway Administration, Office of Research, Washington, D.C., 1972.

Sahuaro performs a laboratory test to determine viscosity as a function of time for a given temperature. Typically the viscosity increases with stirring time, at a constant temperature, until a maximum viscosity is reached. The viscosity then decreases with time, but more slowly than it increased with stirring time. The point on the curve at which the abrupt change in slope occurs has been considered the optimum for mixing the rubber and hot asphalt for a given temperature. Such a test can be performed in the field on a representative sample of material withdrawn from the distributor truck; however, its reliability and usefulness must be proven.

Upon examining the titles in the bibliography, one notes that a substantial effort has been made in the laboratory to try various tests on asphalt-rubber. These general tests may be useful as comparative tests on various combinations of asphalt and rubber as well as on variations of different asphalt cements and different rubbers in combination. The basic problem with predicting the performance of asphalt-rubber, however, lies in the magnitude of the work required. According to Endres,

> There has been a somewhat common misconception on the part of the uninitiated that all synthetic rubbers are alike. Certainly the behavior of the different types in asphalt and the effect on its properties are quite dissimilar. Conversely, a given type of rubber will perform differently in different asphalts. This all adds to the confusion and is one of the reasons why . . . asphalt technologists have been hesitant to undertake the extensive evaluation programs of rubberized asphalts. The numerous types and modifications of synthetic rubber available coupled with the many classes of asphaltic bitumen would be enough to discourage even the most ardent investigators (Reference 3).

ASPHALT-RUBBER CONCRETE

At present, no case exists for the use of asphalt-rubber concrete. Although some laboratory investigations have revealed a positive potential for asphalt-rubber concrete pavements, no positive performance records of such pavements have come to light. Laboratory research has been conducted

(Reference 22) to evaluate the effect of reclaimed rubber (in asphalt concrete) on the brittle behavior of pavement at low temperatures (0° to 40° F). The object was to test a hypothesis that longitudinal cracking in asphaltic concrete pavements is attributable to the brittleness of the pavement at low temperatures, rather than to base and subgrade failures. Any positive effect of the rubber is a function of test temperature, asphalt grade, asphalt content, rubber grade, and rubber content. The effective combination of asphalt and rubber has to be determined for each case by a series of tests. On the basis of the findings described in Reference 22, it is believed that the addition of a small amount of reclaimed rubber will improve the overall year-round performance of a pavement. The investigation revealed that the best mix for the variables included in the study is 6.25-percent asphalt and 2.0-percent reclaimed rubber. The percentages are based on the total weight of the asphalt-concrete mix.

Unfortunately, no performance records are available for rubberized asphaltic concrete other than those of the Green River, Utah, experiment, and those results are probably, in truth, inconclusive.

Reference

22. Stephens, Jack E., and Mokrzewski, Stanley A., *The Effects of Reclaimed Rubber on Bituminous Paving Mixtures*, School of Engineering, University of Connecticut, Storrs, Connecticut, March 1974.

SECTION VI

PERSPECTIVE, CONCLUSIONS, AND SUMMARY

PERSPECTIVE

The literature on asphalt-rubber is replete with seemingly contradictory statements. In order to rationalize this situation, one may fall back on Dr. Rostlers' observation (Reference 2):

> It can be concluded from the findings presented in the literature that all . . . statements are correct in a qualitative way and thus substantiate the statements made by all investigators that, theoretically, asphalt pavement will benefit from addition of rubber, provided a suitable rubber is added in a suitable manner.

Rubber and asphalt both are very complex materials, and together they defy the best of chemists. Therefore, it seems appropriate to proceed to find a combination that works and stick to it. The developers of the ARCO and Sahuaro processes apparently have done just that. These processes have received more support among highway engineers than other rubberizing, maintenance, or corrective processes, although neoprene asphalt and latex asphalt are not to be entirely discounted.

Rubber in some combination with asphaltic materials has been considered for use as a road paving material for nearly a century. According to the literature some highly successful applications of rubberized roadways were made in Europe, especially by the Germans. Unfortunately, no documentation appears to be available to reveal why these applications were so successful.

The very complex and variable nature not only of rubber but also of asphalt has made most engineers hesitant to use asphalt-rubber combinations in highway construction except on an infrequent experimental basis. Nevertheless, the "weird and wonderful resilient properties of asphalt-rubber" have intrigued the laboratory investigators and have thus kept the idea alive.

Endres (Reference 3) found that conditions that result in an elastic rubber network give the best and most enduring physical properties of the asphalt mixtures and that rubbers which undergo the proper degree of swelling and dispersion will show the desired structure immediately upon cooling. Since the effect of the rubber is purely physical, the distribution and dispersion of the rubber in the asphalt should be as uniform as possible. The degree of dispersion can be determined by microscopic examination under moderately high magnification. Rubbers that do not swell will appear as distinctly chunky masses. Rubbers that dissolve or disperse too completely will either not be visible or will appear as a very fine network. Often the latter is the result of too high a mixing temperature or too active a constituent in the asphalt or cut-back. In this case, the proper structure will usually develop upon aging of the cement or curing of the cut-back.

Until about 1967, very small amounts of rubber (4 percent) were considered adequate for rubberizing asphalt. At about this time, C. H. McDonald pioneered the idea of using as much as 35 percent by weight of rubber tire grindings. He succeeded in making the product work in spite of the theoreticians who said it could not be done. Experience of the California Department of Transportation indicates that the optimum percentage of rubber may not yet have been determined.

There are infinite combination possibilities of type and amount of rubber and type or blend of asphalt cement; thus, laboratory experimentation should be conducted to identify the optimum mix proportions. Today, two companies in Arizona manufacture and market asphalt-rubber with relatively high rubber contents. Within the continental U.S., at least two companies are marketing asphalt-rubber with relatively low rubber contents; one is a neoprene latex and the other is a styrene/butadiene latex. The products of the latter two companies also have smaller rubber particle sizes; therefore, the particles are perhaps more thoroughly dissolved and dispersed within the asphalt than are those of the Arizona companies.

The two Arizona companies, by virtue of the fact that large quantities of rubber with larger particle sizes are used, produce a product with a more extensive sponge-like rubber network. This network reinforces the

asphalt, attenuates inherent and induced tensile stresses, and thus acts to reduce or at least retard fatigue and reflective cracking. To the writers' knowledge, only the Arizona companies claim that their products function as a SAM (or SAMI). An advantage lies with the ARCO process in that conventional equipment is used. With the Sahuaro process, either expensive modified tank truck distributors are required, or special equipment is needed for crack filling.

The Sahuaro process has been in use for eleven years with both good and adverse results. The writers are convinced that consistently good results could be obtained if every detail of a job were performed flawlessly. Most of the adverse results probably are attributable to one of the following errors: incorrect time-temperature mixing of hot asphalt and rubber; job performed under cold or wet ambient conditions; aggregate was not dry, heated sufficiently, or coated adequately; chip spreader did not follow the asphalt-rubber distributor truck closely enough; or rollers did not follow the chip spreaders closely enough.

ARCO has been active for only about three years; therefore, insufficient time has elapsed to permit a sound evaluation of the product in place. The writers have found no reason to believe that one of these two products is superior to the other; however, time may reveal a different answer.

CONCLUSIONS

The effectiveness of asphalt-rubber for controlling or reducing cracking in airfield pavements has not been conclusively demonstrated. There is evidence to indicate that the product might be effective if design and installation conditions are very closely controlled. Although several applications have been monitored, the variations in the design of the experiments have produced ambiguous results. The fact that test procedures are neither standard nor fully understood confounds the experimenters even more.

Two needed tests considered of utmost importance by the writers are (1) a test to determine the degree of compatibility of a given rubber with a given asphalt (the California Department of Transportation has found that not all asphalts combine uniformly with rubber to produce a homogeneous mixture), and (2) a field test to determine whether the asphalt-rubber mixture has been heated long enough at the correct temperature to have reacted suitably for application.

Other desirable tests are those whose results could be used to predict the performance of asphalt-rubber. If enough such data were available, the correct asphalt and rubber combinations could be selected for any given location. All standard asphalt tests have provided numbers based on past experience that can be used to predict future performance of a particular asphalt. Such standard tests may be applicable to asphalt-rubber, but the available data base is not comprehensive enough to enable workers to use these tests to evaluate the product or to predict performance.

According to Rostler,

> Even such simple tests as penetration, softening point, and ductility cannot be determined in a meaningful way if the internal net structure or rubber grains present in the cement interfere with obtaining values characteristic of the continuous phase of the system. Thus, the rubber needs to be thoroughly dispersed in asphalt (Reference 2, p. 143).

Rostler cites the work of J. R. Benson ("A Study of Translucent Asphaltic Films," *Proceedings HRB*, Vol. 17, 1937, pp. 368-383) to show that microscopy is an excellent tool for asphalt-rubber research, particularly in the area of the compatibility phenomenon.

From the research effort expended for this report, the writers feel that the SAMI is the only application of asphalt-rubber that should be recommended for major airfield runways at this time. In view of experience with the Naval Air Stations, SAMs cannot be recommended for military airfield runways, where loose chips could present problems. The danger of foreign object damage to jet engines is too great, especially where there are following aircraft. Elimination of chip-seal applications may rule out the Husky Oil process as well as the TR & C process because the manufacturers of these products use them primarily as a chip seal.

There is no reason at this point, however, to eliminate the possibility of using asphalt-rubber chip seals (SAMs) for pavements where loose chips would not pose a threat. Chip seals could be applicable on low-volume non-jet engine facilities, taxiways, shoulders, aprons, and highways. Since only ARCO and Sahuaro tout their products as retarding crack reflection, these two materials, primarily, should be considered for application.

The authors were unable to locate any documentation of the use of asphalt-rubber as crack fillers or joint sealers. There have apparently been many such applications, but none have been monitored in such a way that definitive statements can be made regarding their serviceability.

It is concluded that excellent applications of asphalt-rubber can be made; however, the state of the art has not advanced to a point at which successful applications are consistently achieved or at which preliminary testing of the material can provide a knowledgeable basis for predicting performance in place. Improvements in quality control of both material and workmanship are needed. Until the problem of achieving consistently good results has been solved, the use of rubberized asphalt should be approached on an experimental basis.

SUMMARY

1. The high rubber content of asphalt-rubber mixtures apparently offers the greatest likelihood of success as a means of retarding reflective cracking in pavements.

2. Asphalt-rubber chip seals should be considered for use only on facilities where loose chips would not pose a threat to aircraft (i.e., runways with low volume, non-jet engines, and no close-following aircraft operations; taxiways; shoulders; aprons; and base highways).

3. A stress-absorbing membrane interlayer of asphalt-rubber should be investigated in conjunction with a conventional asphaltic concrete overlay.

4. There is no present documentation to verify that the asphalt-rubber material actually seals joints and cracks in pavements. Further, there is no documented evidence that the material even performs well as a crack and joint filler.

5. The asphalt-rubber membranes are promoted as sealers for sub-surface stabilization and pond liners. Both applications might prove worthwhile.

6. Asphalt-rubber mix design parameters (e.g., percentage and type of rubber and asphalt) should be developed.

7. Test procedures are needed for determining the compatability of a given rubber and a given asphalt and for determining in the field whether the asphalt-rubber mixture has been heated and mixed properly.

8. Field and laboratory test data should be correlated so that the performance of an asphalt-rubber mixture could be predicted on the basis of laboratory tests.

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APPENDIX A
GUIDE SPECIFICATIONS FOR SAHUARO STRESS-ABSORBING MEMBRANE

STRESS-ABSORBING MEMBRANE (SAM): Guideline Specifications[1]

Construction Materials:

<u>Asphalt-Vulcanized Rubber Materials</u>:

The asphalt to be used shall have a maximum penetration of 150 when tested in accordance with procedures outlined by the American Association of State Highway Officials.

The granulated crumb rubber (100% vulcanized) shall meet the following requirements:

Passing Sieve	Percent
# 8	100
# 10	98-100
# 30	0-10
# 40	0-4

The sieves shall comply with the requirements of AASHTO-92.

Note

Specific standards for sampling and testing of granulated crumb rubber have not yet been established. Until standards are established, it is recommended that the granulated crumb rubber be accepted if accompanied by a certificate of compliance from the supplier that the material has been tested during the grinding process and meets the gradation as specified.

The specific gravity of the material shall be 1.15±0.02 and shall be free of fabric, wire or other contaminating materials, except that up to four percent of calcium carbonate may be included to prevent the particles from sticking together.

Footnote

[1] The material presented here is taken directly from the Sahuaro Petroleum and Asphalt Company publication dated June 1, 1978.

Cover Materials

Cover material shall be clean crushed rock or clean crushed gravel conforming to the requirements of AASHTO M78-64. The material shall meet the gradation limits of either No. 7 or No. 8, as shown in section 4.3 of AASHTO M78-64.

Aggregate may be preheated and/or precoated with 0.5 to 0.75 percent paving grade asphalt.

The contractor shall submit a minimum 75 pound sample of cover material to the engineer for testing at least ten calendar days prior to the application of cover material.

Cover materials will be measured by the ton.

Payment for this work will be made at the contract unit price per ton for - COVER MATERIALS, which price shall be full compensation for the item complete, including spreading, rolling and brooming, as hereinafter described and specified.

The Bidding schedule reflects a quantity based on one application as hereinafter specified; however, no adjustment in the contract unit price will be made because of an increase or decrease in the quantity utilized to complete the work under this item.

Blotter Material (Sand) As Necessary

No source of blotter material is designated. Commercial sources or any source should be allowed, providing the material complies with the specifications.

The sand used for blotter should meet the following gradation:

Sieve Size	% Passing
3/8"	100
# 4	80-100
# 16	45-80
#200	9-15

Payment for this work will be made at the contract unit price per ton for - BLOTTER MATERIAL, which price shall be full compensation for the item complete, including spreading, rolling and brooming, as hereinafter described and specified.

The bidding schedule reflects a quantity based on one application as hereinafter specified; however, no adjustment in the contract unit price will be made because of an increase or decrease in the quantity utilized to complete the work under this item.

Construction Details

Mixing Asphalt-Vulcanized Rubber Material

The percentage of granulated, vulcanized rubber shall equal 33-1/3 percent ±2 percent of the asphalt weight.

All equipment utilized in the mixing and application of the asphalt-rubber material shall include the following:

A self-powered distributor equipped with a separate power unit, a distribution pump capable of spraying the specified material at the specified rate through the distributor tips, and equipment for heating and mixing the bituminous material.

The spray bar on the distributor shall be fully circulating. The distributor tips shall remain in such intimate contact with the circulating asphalt that they will not become partially plugged, thereby causing streaked or irregular distribution of the asphalt-rubber composition. Any distributor that produces a streaked or irregular distribution of the material shall be promptly corrected or removed from the project if not corrected.

Distributor equipment shall include a tachometer, pressure gates, volume measuring devices, mixing equipment, and a thermometer. The spray bar on the distributor shall be controlled by a bootman riding in such a position that all sprays are in his full view and are readily accessible.

Mixing equipment capable of producing a homogeneous mixture of rubber and asphalt so that separation does not occur, and designed and operated so that the engineer can readily determine the percentages, by weight, of each component being incorporated into the mixture.

The materials shall be combined as rapidly as possibly for such a time and at such a temperature that the consistency of the mix approaches that of a semi-fluid material. The temperature of the asphalt shall be between 350 and 395 degrees F.

After the full reaction described has occurred, the mix may be cut back with diluent. The maximum amount of diluent used shall not exceed 7-1/2 percent, by volume, of the hot-asphalt-rubber composition as required for adjusting the viscosity for spraying or better "wetting" of the cover material.

The diluent shall have a boiling point of not less than 350 degrees F. and the temperature of the hot asphalt-rubber shall not exceed 350 degrees F. at the time of adding the diluent.

If a job delay occurs after the full reaction has taken place, the material may be slowly reheated to an acceptable spraying temperature with no detrimental effect. It is important, however, because of the polymer reversion that can occur when ground rubber is held for prolonged high temperatures, that the material not be reheated to temperatures above 350 degrees F.

Application of the Asphalt-Vulcanized Rubber (SAM)

The existing pavement shall be cleaned prior to the application of the tack coat.

After cleaning and prior to the application of the membrane seal, the existing pavement surface shall be treated with a tack coat. It is not recommended that "cut-back" asphalt be used for tack coats.

Placement of the asphalt-rubber stress absorbing membrane shall be made only under the following conditions:

(1) The ambient air temperature is about 50 degrees F.

(2) The pavement is absolutely dry, and

(3) The wind conditions are such that satisfactory membrane can be achieved.

Note

Adjustments may be made for locally, seasonal conditions.

The distributor shall be equipped with an internal mixing device capable of maintaining a completely homogeneous blend of the ingredients.

The distributor shall be capable of spreading the asphalt-rubber mixture at the specified rate and the maximum deviation shall not exceed .05 of a gallon per square yard.

The hot asphalt-rubber mixture shall be applied at a rate of 0.45 to .70 of a gallon per square yard (based on 8-12 pounds per hot gallon), depending on aggregate size, roadway surface conditions, etc.

Transverse joints shall be made by placing building paper over the end of the previous application, and the joining application shall start on the building paper. Once the application process has progressed beyond the paper, the paper shall be disposed of as directed by the engineer.

The spreader shall cease spreading prior to completely emptying the distributor to eliminate any roping or streaking.

All longitudinal joints shall be lapped a minimum of two inches.

Application of Cover Material

Cover material shall be immediately applied to the asphalt-rubber material at the rate specified by the engineer.

At the time of application to the roadway, cover material shall be at least as dry as material dried in accordance with the requirements of Section 4.2 of AASHTO T-85.

Application of Blotter Material, as necessary

The Blotter Material shall be at least as dry as material dried in accordance with the requirement of Section 4.1 of AASHTO T-84 at the time of application.

It is suggested that immediately after the initial pass of the rollers, blotter sand shall be uniformly applied in the amount of five pounds per square yard. Additional blotter sand may be required after opening to traffic and sweeping. The additional blotter sand shall be placed at the locations and rates designated by the engineer.

Rolling

At least three pneumatic rollers shall be provided to accomplish the required rolling. At some locations or where production rates require, fewer rollers may be utilized as directed by the engineer.

It is suggested that the cover material be rolled with pneumatic tired rollers carrying a minimum of 5,000 pounds on each wheel and a minimum air pressure of 100 pounds per square inch in each tire.

Sufficient rollers shall be furnished to cover the width of the spread with one pass. It is imperative that the first pass be made immediately behind the aggregate spreader and if the spreading is stopped for any reason, the spreader shall be moved ahead so that all cover material spread may be immediately rolled. The rolling shall be completed within two hours after the application of the cover material. Four complete passes with the rollers shall be made.

Traffic Control

Except for times when it is necessary that hauling equipment and/or pilot trucks must travel on the newly applied seal coat, traffic of all types shall be kept off the seal coat until it has had time to set properly. The speed of all hauling equipment and pilot trucks shall not exceed 15 miles per hour. The minimum traffic free period shall not be less than two hours.

Removing Loose Cover Material

The power broom used in removing loose cover material shall be a rotary sweeper type.

The initial sweeping should begin at daybreak of the day following the placement and be completed as directed by the engineer.

If, because of temperatures or other causes, there is excessive displacement of embedded cover material, sweeping should be discontinued until such time as there will be a satisfactory retention of cover material. Additional final sweeping should be done and all excess cover material removed from three to five days after the roadway has been opened to traffic.

Method of Measurement and Basis of Payment

The Asphalt-Vulcanized Rubber will be measured and paid for per ton of the mixture under - ASPHALT CEMENT (For Membrane Seal) (150 penetration maximum) (Rubberized), including asphalt, granulated rubber and diluent (based on 7-1/2 pounds per hot gallon).

The Cover Material will be measured and paid for under - COVER MATERIAL, as hereinbefore specified.

The Blotter Material will be measured and paid for under - BLOTTER MATERIAL, as hereinbefore specified.

The tack coat will be measured and paid for per ton under the item Asphalt For Tack Coat, as hereinbefore specified.

APPENDIX B

GUIDE SPECIFICATION FOR ARCO STRESS-ABSORBING MEMBRANE

CONSTRUCTION SPECIFICATION FOR SURFACE TREATMENT[1]

1.0 DESCRIPTION

This work shall consist of the application of a hot asphalt-rubber membrane (ARM-R-SHIELD) to a paved surface and immediately embedding aggregate therein, by spreading and rolling procedures as described below, to form a multilayered aggregate ARM-R-SHIELD surface treatment.

2.0 GENERAL REQUIREMENTS

2.1 Preparation of Existing Surface

Prior to application of the asphalt-rubber membrane, the entire paved surface to be treated shall be cleaned by sweeping, blowing and other methods until free of dirt and loose particles. Pot holes, depressions and other irregularities shall be patched as required. No water shall be present on the surface.

2.2 Seasonal and Weather Limitations

Construction shall not proceed when the ambient temperature has been below 50° F within the previous 12 hours, when rain is falling, or when wind conditions are unfavorable to obtaining a uniform spread. When hot (175-300° F) cover aggregate is used, the above temperature requirements may be waived.

Footnote

[1]The material presented here is taken directly from Arizona Refining Company Specification No. C-201-76.

3.0 MATERIALS

3.1 Asphalt-Rubber

The asphalt-rubber material shall be ARM-R-SHIELD meeting the requirements of Arizona Refining Specification M 101-76.

3.2 Mineral Aggregate

Aggregate to be embedded into the asphalt-rubber membrane shall consist of a hard, clean aggregate such as crushed rock, crushed gravel or crushed slag. It shall be of uniform quality throughout and shall be free from dirt and other deleterious substances. It shall also be essentially dry, with a water content less than 0.5 percent as determined by AASHTO T-142.

The aggregate shall also conform to the following requirements:

a. Gradation - either of the following:

Sieve Size	Coarse Grade % Passing	Medium Grade % Passing
3/4 in.	100	---
1/2 in.	70 - 90	100
3/8 in.	0 - 40	70 - 90
No. 4	0 - 5	0 - 10
No. 200	0 - 2	0 - 2

b. Wear Resistance
Loss in Los Angeles Rattler
(after 100 revolutions) ASTM C-131 10 max.

c. Crushed Faces
At least 75% by weight of the material retained on the No. 4 sieve shall have at least one rough, angular surface produced by crushing.

3.3 Certification

Prior to application, the Contractor shall submit certifications of specification compliance for all materials.

4.0 EQUIPMENT

4.1 Distributor Truck

At least one pressure-type bituminous distributor truck in good condition will be required. The distributor shall be equipped with an internal heating device capable of even heating of the material up to 425° F; have adequate pump capacity to maintain a high rate of circulation in the tank; have adequate pressure devices and suitable manifolds to provide constant positive cut-off to prevent dripping from the nozzles. The distribution bar on the distributor shall be fully circulating. Any distributor that produces a streaked or irregular distribution of the material shall be promptly repaired or removed from the project.

Distributor equipment shall include a tachometer, pressure gauges, volume measuring devices, and a thermometer for reading temperature of tank contents.

It shall be so constructed that uniform applications may be made at the specified rate per square yard within a tolerance of plus or minus 0.05 gal./sq. yd.

4.2 Chip Spreader

A self-propelled chip spreader in good condition of sufficient capacity to apply the aggregate within the time period specified will be required. The spreader shall be so constructed that it can be accurately gauged and set to uniformly distribute the required amount of aggregate at regulated speed.

4.3 Brooms

Revolving and drag brooms shall be so constructed as to sweep clean or redistribute aggregate without damage to the asphalt-rubber membrane or surface treatment.

4.4 Pneumatic-Tired Roller

There shall be at least two multiple wheel self-propelled pneumatic-tired rollers with provisions for loading to eight to twelve tons as deemed necessary. Pneumatic-tired rollers shall have a total compacting width of at least 60 inches and shall have minimum tire pressure of 60 pounds per square inch.

4.5 Trucks

Trucks of sufficient number and size to adequately supply the material will be required.

5.0 CONSTRUCTION DETAILS

5.1 Application of ARM-R-SHIELD

The asphalt-rubber material shall be applied by pressure distributor truck within the temperature range of 375-425° F and at a rate of 0.45 to 0.60 hot gallons per square yard. (For estimating purposes, use 7.6 pounds per hot gallon.) If a job delay occurs, the heater in the distributor should be turned off and restarted sufficiently before start of spreading to reheat material to at least 375° F prior to resumption of spreading. No spread shall be in excess of a length which can be immediately covered with aggregate.

The application from the distributor shall be stopped before the tank is empty to be sure the application does not run light. At all startings, intersections, and junctions at transverse joints with

previous spreads or other pavements, provision shall be made to insure that the distributor nozzles are operating at full force when the application begins. Building paper or other suitable devices shall be used to receive the initial application from the nozzles before any material reaches the surface at the transverse joint. The paper or device shall be removed immediately after use without spilling surplus material on the surface.

Longitudinal joints shall be reasonably true to line and parallel to centerline. The overlap in application of asphalt-rubber material shall be the minimum to assure complete coverage. Where any construction joint occurs, the edges shall be broomed back and blended so there are no gaps and the elevations are the same, and free from ridges and depressions.

During application, adequate provision shall be made to prevent marring or discoloration of adjacent pavements, structures, vehicles, foliage or personal property.

5.2 Application of Aggregate

The application of aggregate shall follow as closely as possible behind the application of the hot asphalt-rubber material, which shall not be spread further in advance of the aggregate spread than can be immediately covered. Construction equipment or other vehicles shall not drive on the uncovered asphalt-rubber material.

The dry aggregate shall be spread uniformly by a self-propelled spreader at the rate of spread directed by the engineer, generally between 30 and 40 pounds per square yard. Any deficient areas shall be covered with additional material.

Aggregate may be preheated before application but to a temperature not to exceed 300° F. Aggregate may also be precoated with 0.5 to 0.75 percent of asphalt, if required by the engineer.

5.3 Rolling

Rolling shall commence immediately following spread of aggregate. There shall be at least three complete coverages by the pneumatic-tired rollers to embed the aggregate particles firmly into the asphalt-rubber membrane.

5.4 Curing

The completed ARM-R-SHIELD surface treatment should be allowed to cure for a minimum of 2 hours prior to use. If traffic must travel over the surface treatment, it should be controlled to a speed not to exceed 25 miles per hour.

5.5 Sweeping

When the maximum of aggregate has been embedded into the asphalt-rubber membrane, all loose material shall be swept or otherwise removed at such time and in such a manner as will not displace any embedded aggregate or damage the asphalt-rubber membrane.

6.0 MEASUREMENT AND PAYMENT

6.1 Quantities

Quantities subject to payment are as follows:

(1) ARM-R-SHIELD - per ton or gallon

(2) Aggregate - per ton or cubic yard

6.2 Basis of Payment

Payment for ARM-R-SHIELD shall be in full compensation for all labor, use of equipment, and incidentals necessary in furnishing, hauling, heating and applying the material in accordance with these specifications.

Payment for aggregate shall be in full compensation for all labor, use of equipment, and incidentals necessary in preparation of surfaces; furnishing, hauling and spreading aggregate; and rolling and sweeping operations, in accordance with these specifications.

INITIAL DISTRIBUTION

HQ AFSC/DEEE	1
HQ AFRES/DEMM	1
HQ ADCOM/DEMM	1
HQ ATC/DEMM	1
HQ SAC/DEMM	1
HQ USAFE/DEMO	1
HQ PACAF/DEEE	1
HQ MAC/DE	1
HQ TAC/DE	1
HQ AFESC/TST	1
HQ AFESC/DEMM	2
HQ AFESC/RDCF	13
CERF	6
DDC/DDA	2
FAA/RD430	1
HQ AAC/DEE	1
HQ AFLC/DEM	1
AFIT/Tech Library	1
USAWES	1
HQ AUL/LSE 71-249	1

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